Watershed Modeling in Hampton Roads

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WATERSHED MODELING IN HAMPTON ROADS

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Abstract

This report documents the exploration of the tools, techniques and structure needed to establish a regional watershed modeling program in Hampton Roads. A combination of literature review and experimentation with various modeling tools was used to develop a set of recommendations on a regional program. Section one of the report outlines the potential applications for a watershed modeling program in Hampton Roads, section two provides an overview of the structure and components of a generic watershed modeling program and section three contains a description of the testing of two watershed modeling tools and recommendations on the structure and process associated with building a regional watershed modeling capability in Hampton Roads.

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EXECUTIVE SUMMARY

Hampton Roads localities face an increasingly complex set of challenges in managing water quality. Regulatory programs including the Chesapeake Bay Preservation Act, NPDES Stormwater Permits, Wetlands Regulations and Total Maximum Daily Load (TMDL) requirements place very specific land use and stormwater management demands on localities. Programs such as Tributary Strategies and the Chesapeake Bay 2000 Agreement commitments require localities to improve watershed planning in a more general sense. Given continued development pressure and increasingly stringent regulatory requirements, it has become desirable for the HRPDC to develop the capability to model various land use and stormwater BMP scenarios and provide quantitative comparisons of a range of management options. This quantitative information could used by individual localities and the region as a whole in selecting the most effective and efficient solutions to managing nonpoint source water pollution. Identification of cost effective solutions is critical given the limited financial resources available at the local and regional level to meet multiple regulatory requirements.

Watershed modeling has the potential to be used in a broad range of applications in Hampton Roads. As previously mentioned, examination of alternatives for managing non-point source pollution, analysis of cost effective solutions to overlapping regulatory programs (multiple TMDLs in a single watershed), and evaluation of goals and requirements of federal and state programs are among the critically important applications. Another opportunity is the application of watershed modeling in regional land use planning. Questions about the water quality ramifications of various land use patterns arose in conjunction with a regional smart growth study completed in 2003. At the time the staff of the HRPDC was not able to answer those questions. A regional modeling program would position the staff to answer these and other similar questions in the future. Another important capability is the assessment of the role of green infrastructure networks in managing nonpoint source pollution.

The staff of the HRPDC applied for and received a grant from the Virginia Coastal Program to research watershed modeling options for Hampton Roads. This report documents the exploration of the tools, techniques and structure needed to establish a regional watershed modeling program in Hampton Roads. A combination of literature review and experimentation with various modeling tools was used to develop a set of recommendations on a regional program. Section one of the report outlines the potential applications for a watershed modeling program in Hampton Roads, section two provides an overview of the structure and components of a generic watershed modeling program and section three contains a description of the testing of two watershed modeling tools and recommendations on the structure and process associated with building a regional watershed modeling capability in Hampton Roads.

Several watershed modeling tools were evaluated as part of this study. The Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) modeling system, Pollutant Loading Application (PLOAD), Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds (P8), Hydrological Simulation Program-FORTRAN (HSPF) and the Best Management Practices/Low Impact Development Decision Support System (BMP/LID DSS) were reviewed. Two of these tools, PLOAD and BMP/LID DSS, where applied to sub-watersheds in Hampton Roads to evaluate their utility in analyzing pollutant loads and watershed management options. PLOAD is a valuable screening tool for the estimation of pollutant loads. The BMP/LID DSS provides the opportunity to compare the cost and effectiveness of specific best management practices, including low impact development practices. These tools, applied in conjunction with HSPF, will provide a broad range of analytic capability to evaluate management options.

Given the level of effort required for development of a regional program, it will be necessary to proceed in a stepwise fashion to ensure that such a program is cost-effective and meets local goals. Based on the literature review, analysis of various watershed modeling programs and testing of various watershed models, the following conclusions and recommendations are offered:

- The HRPDC staff should continue discussions with the Hampton Roads localities on the development of a regional watershed modeling program.

- A technical advisory committee should be established to continue the process of articulating the goals and structure for a regional watershed modeling program.

- HRPDC staff should continue to closely monitor the evolution of various water quality regulatory programs and continue to investigate the application of watershed modeling to assist with regulatory compliance.

- HRPDC staff should continue to investigate the application of the BMP/LID and HSPF models in Hampton Roads.

- HRPDC staff should participate in training activities associated with the development and release of the Phase Five Chesapeake Bay watershed model and the associated Community Modeling Program.

- HRPDC staff should participate in BASINs training when the new version of BASINs is released.

Based on the continued discussions with Hampton Roads localities and the work of the technical advisory committee a final set of recommendations on the structure and goals for a regional watershed modeling program should be developed. At this point it will be possible to estimate the cost and level of effort associated with program startup. This is the point at which a regional decision should be taken on moving forward with a modeling program.

WATERSHED MODELING IN HAMPTON ROADS

1.1 Introduction

The localities in the Hampton Roads Planning District face an increasingly complex set of challenges in managing nonpoint source pollution. A combination of population growth and redistribution of existing population is causing continued conversion of rural and agricultural areas to suburban and urban uses within the planning district. Regulatory programs including the Chesapeake Bay Preservation Act, NPDES Stormwater Permits, Wetlands Regulations and Total Maximum Daily Load (TMDL) requirements place very specific land use and stormwater management demands on localities. Programs such as Tributary Strategies and the Chesapeake 2000 commitments require localities to improve watershed planning in a more general sense. Given the continued development pressure and increasingly stringent regulatory requirements it has become desirable for the HRPDC to develop the capability to model various land use and stormwater BMP scenarios and provide quantitative comparisons of a range of management options. This quantitative information could be used by individual localities and the region as a whole in selecting the most effective and efficient solutions to managing nonpoint source pollution. Identification of cost effective solutions is critical given the limited financial resources available at the local and regional level to meet multiple regulatory requirements. The results of the quantitative analysis will be of use to the Hampton Roads localities in a broad range of land use planning activities in addition to compliance with specific regulatory programs.

This report documents an exploration of the tools, techniques and structure needed to establish a regional watershed modeling program in Hampton Roads. A combination of literature review and experimentation with various modeling tools was used to develop a set of recommendations on a regional program. Section one of the report outlines the potential applications for a watershed modeling program in Hampton Roads, section two provides an overview of the structure and components of a generic watershed modeling program and section three contains a description of the testing of two watershed modeling tools and recommendations on the structure and process associated with building a regional watershed modeling capability in Hampton Roads.

1.2 Potential Applications for a Hampton Roads Watershed Modeling Program

Watershed modeling has the potential to be used in a broad range of applications in Hampton Roads. Examination of alternatives for managing non-point source pollution, analysis of cost effective solutions to overlapping regulatory programs (multiple TMDLs in a single watershed), and evaluation of goals and requirements of federal and state programs are among the critically important applications. The ability to perform cost/benefit analysis for various management scenarios is one of the most intriguing possibilities. The cost of compliance with regulatory requirements to manage nonpoint source pollution will likely justify the expense of modeling management alternatives. Another possibility is the application of watershed modeling in regional land use planning. Questions about the water quality ramifications of various land use patterns arose in conjunction with a regional smart growth study completed in 2003. At the time the staff of the HRPDC was not able to answer those questions. A regional modeling program would position the staff to answer these and other similar questions in the future. Another important capability is the assessment of the role of green infrastructure networks in managing nonpoint source pollution. Finally, the evaluation of development impacts will be critically important in managing water quality.

2.0 WATERSHED MODELING OVERVIEW

2.1 Introduction

Watershed modeling is a complex process that requires a significant commitment of time and energy to assemble the data, tools and expertise necessary to digitally replicate critical watershed processes. That being said, properly calibrated and verified models have analytic and predictive capabilities that are essential in evaluating and comparing watershed management strategies. As the costs associated with addressing point and nonpoint source water pollution continue to grow, the development of this expertise will be essential to watershed management in Hampton Roads.

2.2 Elements of a Watershed Modeling Program

A framework must be established to insure that the modeling effort correctly represents conditions in the watershed. This framework includes articulation of goals, selection of tools, data collection and verification of the integrity of the modeling effort.

2.2.1 Articulation of Goals

Articulation of the goals for a watershed modeling program is an important first step in determining the correct tools and level of effort that will be required to solve watershed based problems. If the goal for the program is a generalized assessment of watershed conditions, then a relatively simplistic modeling tool may be appropriate. If identification and analysis of specific problems and comparison of specific management alternatives is required, then the more sophisticated and complex tools will be required. Clear definition of goals will help to insure that the cost and level of effort associated with a modeling program are appropriate for the problem at hand.

2.2.2 Selection of Tools

Watershed modeling is a field that has evolved in parallel with advances in computer technology. A sophisticated range of modeling tools is available for a broad range of applications. Given the large range of options available, one of the difficult steps in solving watershed-based problems is the selection of the correct modeling tools. The tools range in complexity from relatively simple models for general watershed characterization to detailed models that support analysis and comparison of differing management scenarios. As the tools increase in complexity and predictive power, the sophistication of the input data and the level of expertise required of the model users also increases. Given the time commitment and cost involved in running the more sophisticated models, it is necessary to carefully evaluate the watershed assessment needs and select a modeling tool that closely matches the requirements of a given project. *(Information from Compendium of Tools for Watershed Assessment and TMDL Development, USEPA Office of Water, May 1997 (Developed by Tetra Tech, Shoemaker, et al))*

The United States Environmental Protection Agency is an important source of both watershed modeling tools and information about their use for various watershed assessment applications. The Compendium of Tools for Watershed Assessment and TMDL Development, (USEPA Office of Water, May 1997) provides a review and assessment of a broad range of modeling tools including watershed scale loading models, field scale loading models, receiving water models and integrated modeling systems. The loading models are intended to predict pollutant movement from the land surface to water bodies. The field scale models address the same issues but operate on a smaller geographic scale than watershed scale models. As the name implies, the receiving water models are intended to predict the impacts of pollutant loading on the receiving water body. Integrated modeling systems link loading models and receiving water models, sometimes including a GIS interface and data base system. The majority of the models presented in this analysis have been developed or sponsored by federal and state agencies. Universities and private companies developed a smaller number of models.

The watershed loading models analyzed by the EPA are presented in a three-tiered hierarchy that includes simple methods, mid-range models, and detailed models. Simple methods typically rely on large-scale aggregation of land use/land cover information and estimations of various categories of input data. Simple methods provide rough estimates of sediment and pollutant loading and have limited predictive capability. Mid-range models are more reliant on site-specific data than simple methods and feature a more sophisticated representation of the generation and transport of pollutants. Mid-range models are useful for preliminary, qualitative evaluations of BMP alternatives. Detailed models offer the best representation of watershed processes affecting pollution generation. When properly applied and calibrated, detailed models can provide accurate predictions of variable flows and water quality at any point in a watershed. The additional precision provided by the detailed models comes at the expense of considerable time and resource expenditure for data collection and model application.

2.2.2.1 Individual Model Suites/Models

The following section provides a brief overview of several commonly available watershed models. The BASINS system is an entire modeling framework developed by the U.S. EPA. BASINS includes several watershed models such as PLOAD and HSPF. Other models described include P8 and BMP/LID.

2.2.2.1.1 BASINS

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) is an integrated modeling framework developed by the U.S. Environmental Protection Agency. Major components of BASINS include databases containing watershed information, assessment tools, data manipulation utilities, watershed and water quality models and post-processing tools. The national databases include spatially distributed data such as land use/land cover and hydrologic unit boundaries, environmental monitoring data such as water quality monitoring station summaries and weather station sites, and point source data such as industrial facility discharge sites and toxic release inventory sites. This information is typically a good starting point for local studies but must be augmented with local data to provide a complete picture of local conditions. The assessment tools include TARGET, a tool that supports broad-based evaluation of a watershed's water quality and/or point source loadings and ASSESS, which supports analysis of water quality stations and discharge facilities. The data manipulation utilities include data mining tools, a utility for the creation of watershed characterization reports, a tool for watershed delineation and tools for land use reclassification. The modeling tools include the Hydrologic Simulation Program-FORTRAN (HSPF), the Soil and Water Assessment Tool (SWAT), PLOAD and QUAL2E.

2.2.2.1.2 PLOAD

The GIS Pollutant Loading Application (PLOAD), developed by CH2M HILL, is a simplified, GIS based model used to calculate pollutant loads for watersheds. As part of the BASINS package, PLOAD utilizes the ArcView 3.x platform. PLOAD estimates nonpoint sources (NPS) of pollution on an annual average basis for any user-specified pollutant. The user may calculate the NPS loads using either the export coefficient or the EPA's Simple Method approach.

In general, the simple method is used for watersheds comprised primarily of urban land uses, and the export coefficient approach is applied in watersheds composed mainly of rural land uses. The Simple Method is an empirical approach developed for estimating pollutant export from urban development sites in the Washington DC, area (Schueler 1987). Its application is limited to small drainage areas of less than one square mile (EPA 1997). The Simple Method has been endorsed by EPA as a viable screening tool for NPDES stormwater projects (EPA 1992). The export coefficient approach can be applied to any size watershed containing mixed land uses.

The PLOAD application requires pre-processed GIS and tabular input data as listed below:

- GIS land use data
- GIS watershed data
- GIS BMP site and area data (optional)
- Pollutant loading rate data tables

• Impervious terrain factor data tables

• Pollutant reduction BMP data tables (optional)

• Point source facility locations and loads (optional).

The pollutant loadings are based upon nonpoint pollution loading factors that vary by land use and the percent imperviousness associated with each land use type. The land use types and pollutants are linked via an Event Mean Concentration value, which defines the concentrations of specific pollutants within each land use type. Impervious factors for land uses as well as event mean concentrations can be extrapolated from national data sets or can be calculated from site-specific data.

This model is a useful tool that provides an overall perspective of a watershed’s pollutant loadings from storm water runoff. The PLOAD model can show the relative impact to the watershed based on specific land use changes or implementation of Best Management Practices (BMPs). The PLOAD model does not show the impact of development on a site-specific scale, but rather on a watershed wide scale. Additionally, the model should not be used as a final calculation of exact loadings, but rather should be used to show which sub-basins within a watershed are likely to have relatively higher or lower concentrations of storm water pollutants.

2.2.2.1.3 Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds (P8)

P8 is a model for predicting the generation and transport of stormwater runoff pollutants in urban watersheds. Continuous water-balance and mass-balance calculations are performed on a user-defined system consisting of watersheds, stormwater management devices, particle classes, and water quality constituents.

Simulations are driven by continuous hourly rainfall and daily air temperature time series. The model has been developed for use by engineers and planners in designing and evaluating runoff treatment schemes for existing or proposed urban developments. The model is initially calibrated to predict runoff quality typical of that measured under the EPA's Nationwide Urban Runoff Program for Rhode Island rainfall patterns. Predicted water quality components include suspended solids (five size fractions), total phosphorus, total Kjeldahl nitrogen, copper, lead, zinc, and total hydrocarbons.

Primary applications include site BMP design to achieve total suspended solids removal efficiencies. Simulated BMP types include detention ponds (wet, dry, extended), infiltration basins, swales, and buffer strips. Hydrologic components of the program are calibrated and tested against six years of daily streamflow data from the 15,000-acre Hunt-Potowomut watershed, Rhode Island. The model is used to examine the water quality implications of alternative treatment objectives.

Inputs are structured in terms that should be familiar to planners and engineers involved in hydrologic evaluation. Several tabular and graphic output formats are provided. The computer program runs on IBM-PC compatible microcomputers. The P8 Urban

Catchment Model - User's Manual, IEP Inc., 1990 provides an overview of the model and several example applications.

2.2.2.1.4 HSPF

2.2.2.1.4.1 Brief History

HSPF has undergone a 40-year development process and is among the most sophisticated watershed models available. The core of HSPF was developed at Stanford University in the early 1960's as the Stanford Watershed Model (SWM). Over the years the program has been expanded to include a broader range of capabilities. In the 1970's water quality simulation capabilities were added and the name was changed to the Hydrocomp Simulation Program (HSP). During this same period the USEPA sponsored the development of the Agricultural Runoff Management (ARM) model and Nonpoint Source (NPS) loading model. Subsequently the EPA sponsored a project to combine these capabilities and recode the entire package in FORTRAN, resulting in the Hydrological Simulation Program-FORTRAN (HSPF).

2.2.2.1.4.2 Applicability:

HSPF is a tool that can be used for a broad range of applications ranging from initial screening to assessing pollutant loading in complex watersheds through both continuous and storm event simulation. Management alternatives can be compared including evaluation of BMP design criteria. HSPF is capable of calculating surface and subsurface pollutant transport from complex watersheds to receiving waters.

2.2.2.1.5 BMP/LID

The development of the stormwater BMP Decision Support System (BMP/LID DSS) is a joint venture of Prince George's County, Maryland and the U.S. Environmental Protection Agency (EPA) Office of Research and Development. The system is a decision-making tool for the placement of BMPs at strategic locations in urban watersheds. The focus is on evaluating the effectiveness of BMPs labeled as Low Impact Development (LID), but it also includes the option for placing traditional BMPs. LID stands apart from other approaches because of its emphasis on cost-effective, lot-level strategies that closely reproduce the pre-development hydrology and reduce the impacts of development.

The system employs ESRI ArcGIS as the platform, and it provides GIS-based visualization and support for developing networks that include sequences of land uses, BMPs, and stream reaches. The system also provides interfaces for BMP placement, BMP attribute data input, and decision optimization management. The system includes a stand-alone BMP simulation and evaluation module that allows flexibility in examining various BMP design alternatives. Process-based simulation of BMPs provides a technique that is sensitive to local climate and rainfall patterns. The system incorporates a meta-heuristic optimization technique to find the most cost-effective BMP placement and implementation plan given a control target or a fixed cost.

The data requirement for BMP/LID DSS is relatively low. In order to delineate the watershed using the manual delineation tool, the system requires only a land use data layer in grid format, a land use lookup table (containing land use code, land use name, and land use description). In order to use the automatic delineation tool in BMPDSS, additional data for watershed topography and hydrography is needed. The U.S. Geological Survey's (USGS) Digital Elevation Model (DEM) or a local digital contour map can be used to derive watershed topology. For hydrography, delineated stream coverage or USGS's National Hydrography Dataset (NHD) can be used. Currently, the system does not simulate the runoff, flow, nutrient, and sediment time series. It requires an external time series from observed flow data or a watershed simulation model such as HSPF. The time series should be unit area-based and specific for each individual land use type and be in the required format.

The key questions that can be addressed by BMP/LID DSS are: (1) What is the benefit of management? (2) What is the difference between management options/scenarios including one or more practices? (3) What is the cost benefit of each alternative? The potential users of this system include local and county government planners, state and federal regulatory reviewers, public concerned citizen/stakeholder groups, private industry, consultants, and academics.

2.2.3 Data Collection

The input to and output from computer based modeling systems encompasses a broad range of digital data types and formats. Thus, one of the major tasks in assembling a watershed-modeling program is development of a "digital watershed". This compilation of digital data represents the structure and conditions present in the watershed during the time period that is modeled. One of the most important tools for developing and analyzing this digital representation of the watershed is the geographic information systems (GIS). Integration of GIS with a modeling system allows the use of a graphical interface to view and manipulate many elements of the digital watershed.

The quantity and type of digital information needed to represent the watershed depends on the sophistication of the model being used. Models that incorporate a lumped parameter method of computing runoff typically depend on generalized rainfall-runoff relationships such as the NRCS Curve Number Method. Distributed models operate by subdividing the watershed into cells and calculating runoff for each of the cells.

Key elements of the digital watershed include a representation of the hydrographic system being modeled, weather conditions during the time period being modeled, soils and land cover within the watershed and elevation data. Some watershed models require calibration. For those models, monitoring data including flow and pollutant loading are needed.

Paul DeBarry, in his book Watersheds: Processes, Assessment and Management, identifies the following categories of information as being needed to support a watershed modeling program:

- A planimetric base map including features such as the transportation network, utility network and political boundaries.
- Watershed Hydrography: Of primary importance is the stream network within the watershed. This data layer requires connectivity for modeling purposes. The National Hydrography Dataset (NHD) has required connectivity and includes Stahler stream order. (p. 474 of Watersheds) Also important are lakes, reservoirs and wetlands.
- Digital Orthophoto Quadrangles (DOQ) are computer-generated images of aerial photographs in which image displacement caused by terrain relief and camera tilts have been removed. USGS Digital Raster Graphics (DRG) are scanned georeferenced images of USGS standard series topographic maps. Both of these image types are useful in identifying land use patterns and land use change over time.
- Physiographic provinces, ecosystem types and climate information are useful in further characterizing the watershed.
- Digital Elevation Models (DEM) are georeferenced digital files containing terrain elevation. DEMs can be combined with DRGs to create sophisticated topographic maps.
- Digital soils data is available from the National Resources Conservation Service. The Soil Survey Geographic Database (SSURGO) data is available for all of Hampton Roads and most of Virginia.
- Slopes can be determined from a variety of sources including soil surveys and digital elevation models.
- Land Use/Land Cover must be obtained in a form that is compatible with the chosen model(s).
- Other Physical Features such as surface and bedrock geology, floodplains, satellite imagery, aerial photography, habitat and endangered species.
- BASINS data including water quality monitoring station summaries, weather station sites, and point source data such as industrial facility discharge sites and toxic release inventory sites.
- Other watershed-specific data needed to meet the modeling program goals. This information may be in a non-digital form and will require digitization prior to inclusion.

2.2.4 Verification, Calibration and Validation

Watershed modeling is a process that is error prone due to the inherent difficulties of adequately representing natural process. To compensate for these inherent difficulties and the complexity of the models, it is necessary to test and evaluate a model against measurements taken within the watershed being modeled. Steps in this evaluation process are commonly referred to as verification, calibration and validation. Verification is the process of checking the computer code of a given model to insure that the equations that replicate natural phenomenon have been properly entered. Calibration is the process of adjusting model parameters to best match watershed conditions. Validation is the process of testing a calibrated model against different scenarios to insure that the model has the flexibility to replicate a broad range of watershed conditions. The person or team that develops a particular model typically handles verification. Calibration and validation are the responsibility of the person or team that applies the model to solve watershed problems.

The extent to which calibration and validation are possible and necessary is dependent on both the complexity of the model and the availability of field measurements and other data to benchmark the model. Simple models that are suitable primarily for watershed screening are typically intended for a quick look at watershed conditions. An extensive calibration and validation process would not be warranted for a simple model given the generalized nature of its predictive power. In contrast, sophisticated models such as HSPF cannot be reliably run without extensive calibration and validation. When available, field measurements taken in the watershed being modeled should be used for calibration and validation. If field measurements are not available, statistical frequency analysis or regression methods must be used.

2.2.5 Model Application

Once the preceding steps are complete, it will be possible to apply the model to answer questions and examine watershed management alternatives. Watershed models are particularly well suited for relative comparison of the efficacy of various management scenarios. The ability to perform cost / benefit analysis of management alternatives prior to implementation is one of the most convincing arguments in favor of establishment of a watershed modeling program. Absolute prediction of pollutant loadings is also possible but is somewhat more problematic given the impossibility of completely representing all aspects of a watershed in a digital model.

3.0 DEVELOPMENT OF A WATERSHED MODELING PROGRAM IN HAMPTON ROADS

3.1 History

Many projects and studies in Hampton Roads have involved watershed modeling. The majority of these efforts have been examinations of specific watersheds within the region rather than attempts to build a comprehensive regional modeling capability. As a result, the previous efforts are of limited utility in building a regional program. Going forward there are two efforts that may contribute significantly to the development of a regional program. The first is the development of Total Maximum Daily Loads (TMDLs) for many water bodies in Hampton Roads. The second is the development of the Phase Five Chesapeake Bay watershed model. The Phase Five model will include all of Hampton Roads. Previous versions of the Chesapeake Bay watershed model ended at the southern terminus of the Bay watershed, leaving out the headwaters of the Albemarle-Pamlico system.

3.1.1 Hampton Roads Water Quality Management Plan

One of the first intensive examinations of water quality issues in Hampton Roads was sparked by the adoption of the Federal Clean Water Act. The Hampton Roads Water Quality Agency developed the Hampton Roads Water Quality Management Plan in 1978. This initiative including watershed modeling to characterize nonpoint source pollutant loading to water bodies in Hampton Roads. While this effort included the entire Hampton Roads region the modeling tools utilized are now significantly dated, limiting their utility for use in a regional program.

3.1.2 Stormwater Permits

Watershed modeling has been performend for several of the Hampton Roads localities as part of their NPDES MS4 stormwater programs. The PLOAD model was used to assess nonpoint source loadings based on land use types and BMP location. This work is applicable for future evaluations of the ramifications of land use change on nonpoint source pollutant loading. Unfortunately, due to the simplifying assumptions made in PLOAD, it has limited applicability for examining alternative BMP scenarios.

3.2 Current Efforts

3.2.1 Total Maximum Daily Load Determination and Compliance

The development of Total Maximum Daily Loads (TMDLs) for impaired waters in Hampton Roads has involved extensive watershed modeling. The bulk of this work has involved application of the Hydrologic Simulation Program – Fortran (HSPF) model to assess the role of both point and non-point source pollutants in causing various water quality problems. This work will be useful in helping to establish a library of time series and calibration data that can be utilized in future modeling efforts. In addition the model runs provide analysis of loading and management measures required for specific pollutants.

3.2.2 Lynnhaven River Study

The Lynnhaven River is currently one of the most intensely studied water bodies in Hampton Roads. This effort involves the City of Virginia Beach, the United States Army Corps of Engineers, the Virginia Institute of Marine Science, the Virginia Department of Environmental Quality and the Hampton Roads Planning District Commission. A TMDL and associated implementation plan have been developed for bacterial contamination of shellfish. The Virginia Institute of Marine Science is currently developing a hydrodynamic model of the Lynnhaven system. In conjunction with this effort, URS is developing a watershed model for the system. HRPDC staff is testing the BMP/LID model in the watershed. With all of this work underway the Lynnhaven will serve as a test bed for future modeling efforts in Hampton Roads.

3.2.3 Chesapeake Bay Program

The Chesapeake Bay Program has been involved in the development and application of an increasingly sophisticated set of watershed models for the characterization and prediction of point and nonpoint pollutant loading to the Chesapeake Bay. Historically, the Chesapeake Bay Program's watershed modeling efforts have included only part of the Hampton Roads region. The dividing line between the Chesapeake Bay watershed and the Albemarle-Pamlico watershed runs directly through Hampton Roads. The newest version of the watershed model (Phase Five) will include all of the land area within Virginia. In addition, the land use/land cover data used in the Phase Five model will be significantly more detailed than in previous versions.

The Chesapeake Community Modeling Program, under development concurrently with the Phase Five model, is intended to support local and regional watershed modeling for TMDL and other pollutant load analysis and management. The Phase Five Community Model will support subdivision of watersheds and recalibration based on the new segmentation. This evolution of the Chesapeake Bay watershed model has the potential to create a significant component of a regional watershed modeling program for Hampton Roads.

3.3 *Evaluation of Tools*

3.3.1 Pload/Simple Method

As previously discussed in Section 2.2.2.1.2, PLOAD provides a generalized load estimate for pollutants within watersheds less than 1 square mile in area. For this project, the simple method was used to compare pollutant loads from an urban watershed and a rural watershed within the City of Virginia Beach.

PLOAD has previously been applied in the Hampton Roads region in order to estimate pollutant loads for inclusion in MS4 annual reports. Land-use specific event mean concentration (EMC) and percent impervious data were applied to GIS layers of land use and drainage basins to develop pollutant loadings. BMP location and pollutant removal efficiency data were used to take the appropriate credit for the structural stormwater controls implemented in the City.

The following data are necessary to calculate pollutant loading using PLOAD:

- GIS land use data
- GIS watershed data
- GIS BMP site and area data (optional)
- Pollutant loading rate data tables
- Impervious terrain factor data tables
- Pollutant reduction BMP data tables (optional)
- Point source facility locations and loads (optional)

When the Simple Method is designated for calculating pollutant loads in PLOAD, two equations are required to calculate the loads for each specified pollutant type. First, the runoff coefficient for each land use type must be derived with the equation:

$$RVU = 0.05 + (0.009 * IU)$$

Where:

RVU = Runoff Coefficient for land use type u, $inches_{run}/inches_{rain}$

IU = Percent Imperviousness

The pollutant loads are then calculated with the following equation:

$$LP = \Sigma\ U\ (P * PJ * RVU * CU * AU * 2.72 / 12)$$

Where:

LP = Pollutant load, lbs

P = Precipitation, inches/year

PJ = Ratio of storms producing runoff (default = 0.9)

RVU= Runoff Coefficient for land use type u, $inches_{run}/inches_{rain}$

CU = Event Mean Concentration for land use type u, milligrams/liter

AU = Area of land use type u, acres

The PLOAD user enters the precipitation and storm ratio values interactively. The loading rates are derived from the EMC tables, while the land use areas are interpreted from the land use and watershed GIS data.

The data used to calculate the pollutant loads for the urban and rural test cases is discussed in detail in the following sections. The location of these two test watersheds is shown in Figure 1.

3.3.1.1 Test Cases

Two watersheds within Virginia Beach were selected as test cases in order to compare the pollutant loading estimates for a rural and urban watershed. The urban watershed selected occupies 150 acres within the Thalia Creek drainage basin (Figure 2). The 1505-acre watershed selected for the rural test case is located in the southern portion of Virginia Beach between the North Landing River and Back Bay (Figure 3).

The urban watershed is the same one that will be used to test the BMP/LID Decision Support System. This urban watershed was chosen because it has been built out since the early 1990s, it has an existing stormwater detention pond, it possesses potential for constructing LID retrofits, and it is located within the Lynnhaven River watershed, which is being studied extensively as part a Corps of Engineers Restoration Study. These qualities were important in order to have the necessary data available and to be able to compare the effectiveness of traditional and LID BMPs. The rural watershed was selected because it is a relatively small watershed that still has a large percentage of agricultural and marsh lands. Modeling an urban and a rural watershed provides an opportunity to compare the pollutant loads of two watersheds with differing land use compositions.

For this project, watershed boundaries, BMP location and efficiency (Table 1), land use imperviousness (Table 2), and EMC data (Table 3) were taken from the previous study conducted by CH2MHill for the Phase I localities of the Hampton Roads Planning District Commission. EMCs for the City of Virginia Beach were calculated using water quality monitoring data collected from five stormwater outfalls from 1996 through 2001. A detailed description of how these values were calculated can be found in the

CH2MHIll report, “EMC Analysis of Stormwater Monitoring Data, Permit Year 5 – City of Virginia Beach.”

Land use data for 2005 was obtained from the City of Virginia Beach Planning Department. Table 4 displays the percent land area for each land use in the two watersheds and Figure 4 and Figure 5 illustrate the land use compositions of the watersheds. Rainfall totals for 2005 at Norfolk International Airport were utilized in the analysis. Winter (October to March) precipitation totaled 20.67 inches, and summer (April to September) totals were 25.44 inches. Results of the PLOAD analysis are displayed in Table 5.

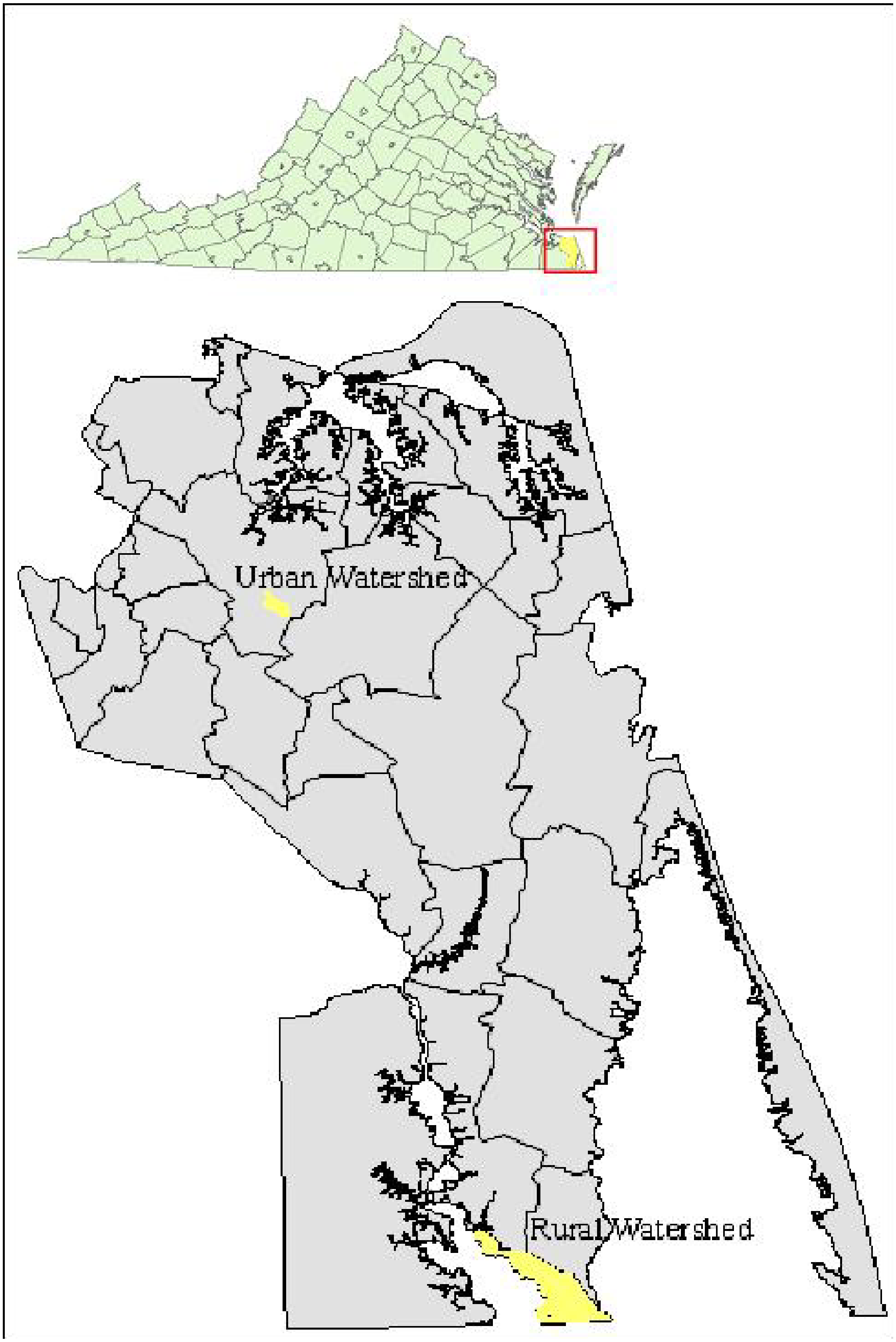


Figure 1 Location of Urban and Rural Test Case Watersheds

Aerial Imagery © 2002 Commonwealth of Virginia

Figure 2 Aerial View of Urban Test Watershed

Aerial Imagery © 2002 Commonwealth of Virginia

Figure 3 Aerial View of Rural Test Watershed

Table 1 Percent Removal Rates for Urban BMP (City of Virginia Beach Removal Efficiencies)

BMP Type	Area Served	BOD_1	TSS_2	TDS_3	COD_4	NOX_5	TKN_6	TP_7	DP_8
Wet Pond	150 acres	30	90	30	30	0	20	50	60

[1] Biochemical Oxygen Demand
[2] Total Suspended Solids
[3] Total Dissolved Solids
[4] Chemical Oxygen Demand
[5] Nitrate and Nitrite
[6] Total Kjeldahl nitrogen
[7] Total Phosphorus
[8] Dissolved Phosphorus

(Source: Pollutant Load Analysis – City of Virginia Beach FY2006)

Table 2 Percent Impervious Values for Land Uses

Land Use	Percent Impervious
Agricultural – Cropland[1]	0.5
Agricultural - Pasture[1]	0.5
Approved Being Developed[3]	20
Commercial[1]	75
Forest[1]	0.5
Industrial[1]	75
Marsh[1]	100
Multi Family[1]	45
Office[1]	75
Park[4]	5
Public/Semi Public[1]	65
Single-Family or Duplex[1]	30
Street Network[1]	90
Town House[2]	40
Undeveloped/Open[1]	0.5
Water[1]	100

Notes:
[1] Source: Table 2-2, City of Virginia Beach, Watershed Management Model.
[2] Source: Table 5-4, City of Newport News, NPDES Stormwater Permit Application Part II.
[3] Represents approximately one-half of the average of Single Family or Duplex and Office land uses.
[4] Estimated from TR-55 (1986) and Northern Virginia Planning District Commission (1994) data.

Table 3 EMC Data for Test Case Watersheds

CITY OF VIRGINIA BEACH EMC BY LAND USE AND SEASON (MG/L)										
LANDUSE	**SEASON**	**BOD**	**TSS**	**TDS**	**COD**	**NOX**	**TKN**	**NH3[6]**	**TP**	**DP**
Residential[1]	Winter	5.6	38.2	103.5	47.1	0.14	1.18	0.15	0.25	0.06
Commercial[2]	Winter	10.4	25.4	32.6	58.5	0.58	1.17	0.48	0.21	0.13
Park/Undeveloped[3]	Winter	8.0	78.0	30.0	45.0	0.61	1.08	0.00	0.14	0.03
Water[3,4]	Winter	3.0	26.0	0.0	22.0	0.60	0.60	0.00	0.03	0.01
Agricultural[3,5]	Winter	3.8	63.4	92.2	49.4	0.12	0.71	0.17	0.48	0.11
Streets[3]	Winter	9.7	104.0	30.0	94.0	0.74	1.65	0.40	0.33	0.17
LANDUSE	**SEASON**	**BOD**	**TSS**	**TDS**	**COD**	**NOX**	**TKN**	**NH3[6]**	**TP**	**DP**
Residential[1]	Summer	10.2	45.2	105.2	58.9	0.24	1.97	0.23	0.35	0.08
Commercial[2]	Summer	10.8	24.0	41.9	71.0	0.75	1.52	0.49	0.25	0.16
Park/Undeveloped[3]	Summer	8.0	78.0	30.0	45.0	0.61	1.08	0.00	0.14	0.03
Water[3,4]	Summer	3.0	26.0	0.0	22.0	0.60	0.60	0.00	0.03	0.01
Agricultural[3,5]	Summer	11.4	187.4	272.6	146.3	0.34	2.09	0.50	1.42	0.33
Streets[3]	Summer	9.7	104.0	30.0	94.0	0.74	1.65	0.40	0.33	0.17
LANDUSE	**SEASON**	**BOD**	**TSS**	**TDS**	**COD**	**NOX**	**TKN**	**NH3[6]**	**TP**	**DP**
Residential[1]	Annual	7.0	38.5	103.1	52.0	0.20	1.67	0.16	0.29	0.07
Commercial[2]	Annual	11.1	24.7	37.6	62.8	0.66	1.33	0.50	0.24	0.15
Park/Undeveloped[3]	Annual	8.0	78.0	30.0	45.0	0.61	1.08	0.00	0.14	0.03
Water[3,4]	Annual	3.0	26.0	0.0	22.0	0.60	0.60	0.00	0.03	0.01
Agricultural[3,5]	Annual	8.0	132.0	192.0	103.0	0.24	1.47	0.35	1.00	0.23
Streets[3]	Annual	9.7	104.0	30.0	94.0	0.74	1.65	0.40	0.33	0.17

[1] Includes – single family or duplex, townhouse, multi-family, military

[2] Includes – commercial, industrial, office, public/semi-public, approved being developed

[3] EMCS taken from Table 2-2 from the City of Virginia Beach's Watershed Management Model User's Manual Version 1.0

[4] Includes - water, wetlands, and BMPs

[5] Agricultural pollutants distributed seasonally based on erosion seasonality associated with local seasonal distribution of precipitation and typical four-year crop rotation (peanuts, cotton, corn, small grain, soybean). Results: Winter EMC = 48% x Annual EMC. Summer EMC == 142% x annual EMC. (See footnote 3 for source of annual EMC)

(Source: Pollutant Load Analysis – City of Virginia Beach FY2006)

Table 4 Land Use Comparison of Urban and Rural Watersheds

Land Use	Rural Acres	Percent Area	Urban Acres	Percent Area
Agricultural - Cropland	382.66	25.43%		
Agricultural - Pasture	93.48	6.21%		
Commercial	199.36	13.25%	29.64	19.71%
Forest	27.62	1.84%		
Marsh	319.33	21.22%		
Multi Family			30.81	20.49%
Office			4.23	2.81%
Park	56.74	3.77%	0.34	0.23%
Public/Semi Public			0.13	0.08%
Single Family or Duplex	384.14	25.53%	24.26	16.13%
Street Network	37.15	2.47%	22.82	15.17%
Town House			25.98	17.28%
Water	4.37	0.29%	12.18	8.10%
Total	1505		150	
Land Use areas calculated from City of Virginia Beach 2005 Tax Parcel Data.				

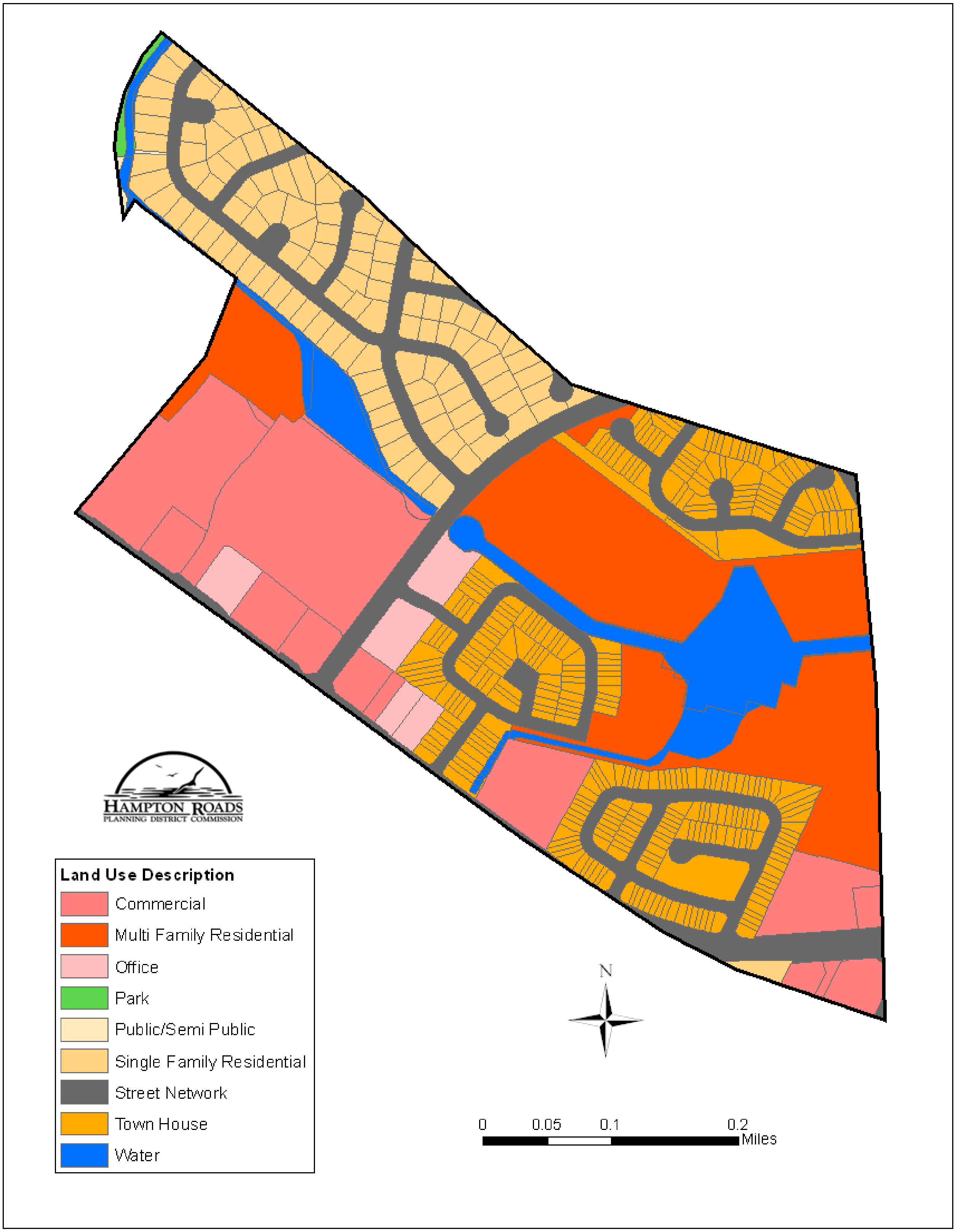


Figure 4 Land Use for Urban Test Case

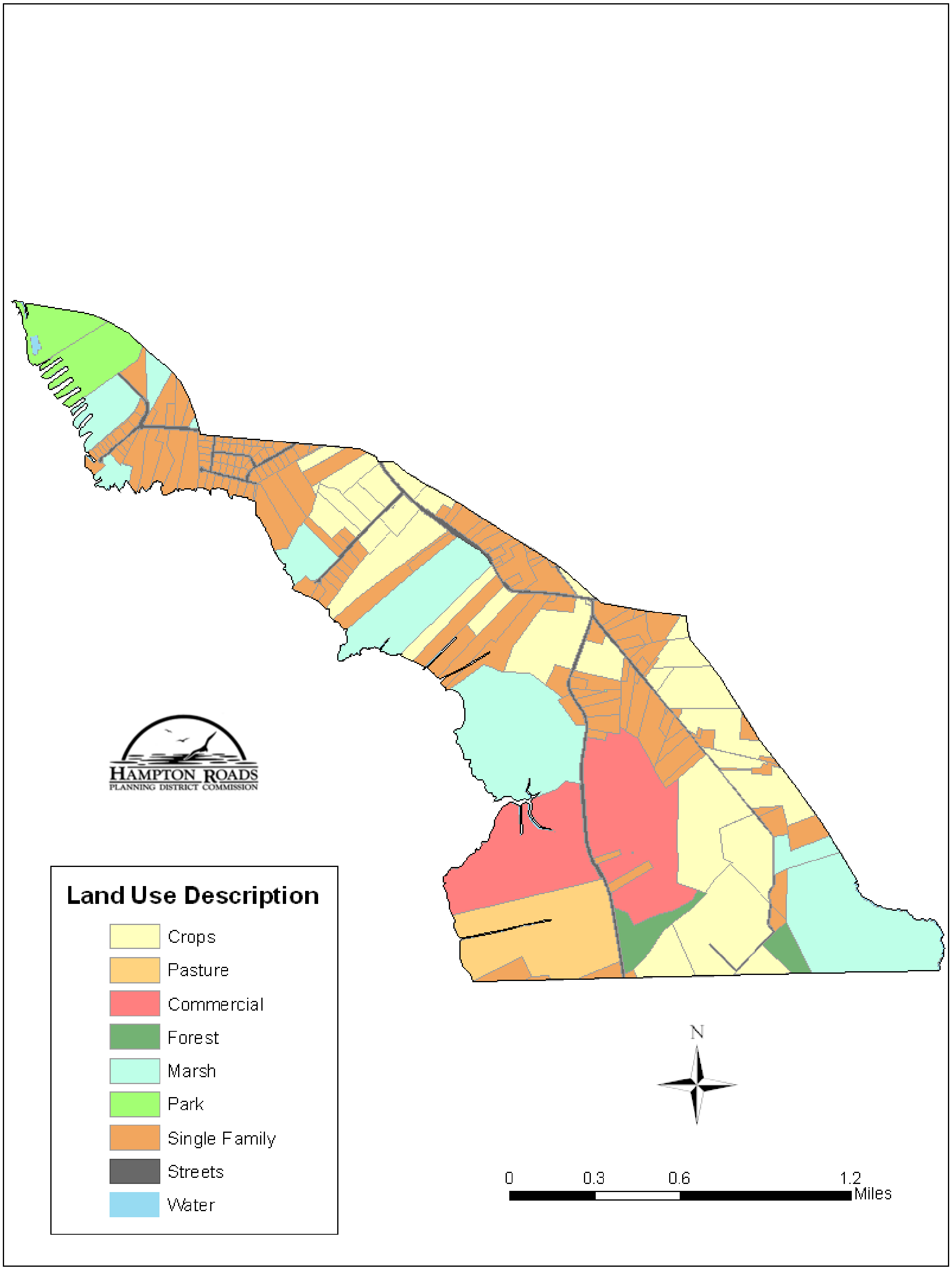


Figure 5 Land Use Map for Rural Test Case Watershed

3.3.1.2 Results of Analysis and Discussion

The results of the pollutant loading analysis are displayed in Table 5. Area weighted pollutant loads for biochemical oxygen demand (BOD), total dissolved solids (TDS), nitrite/nitrate (NOx), total kjeldahl nitrogen (TKN), and total phosphorus (TP) are higher in the urban watershed. Higher loadings of these pollutants were expected in the urban watershed due to the higher percent of developed area and corresponding overall percent imperviousness (Table 6) and the higher event mean concentrations (EMCs) for these pollutants for developed lands (Table 7). Loads of total suspended solids (TSS) and dissolved phosphorus (DP) are higher in the rural watershed. Although less impervious land equates to less runoff in the rural watershed (Table 6), the concentrations of suspended solids and phosphorus are higher in runoff from agricultural lands (Table 7). In addition, the retention basin located in the urban watershed was designed to remove 90 percent of the TSS load and 60 percent of the DP load (Table 1).

Loads in the rural watershed may be overestimated because land uses were derived from tax parcel data. If there is a residence located within a parcel, then the entire parcel is classified as single family residential. Parcels in the rural sections of the city are generally larger than in the urban portions, so the percent impervious areas for single family parcels in rural areas is lower than in urban areas. However, the City of Virginia Beach has only one impervious value for single family residential land use. This number is largely representative of urban lands. Therefore, the overall impervious area for the rural watershed is likely overestimated. For future calculations of pollutant loadings, the City of Virginia Beach should consider deriving a separate impervious value for rural residential lands.

Table 5 PLOAD Results Summary for Test Watersheds (lbs/acre/year)

Predicted Loads	Area (ac)	BOD	TSS	TDS	COD	NOx	TKN	TP	DP
Rural	1505	25.30	150.01	149.72	179.36	2.14	4.25	0.66	0.26
Urban	150	32.89	27.26	214.90	238.73	2.78	6.27	0.69	0.23

Table 6 Test Watersheds Land Use Summary

	Rural Watershed	Urban Watershed
Percent Developed Area	41.25%	91.67%
Percent Undeveloped Area	58.76%	8.33%
Overall Percent Imperviousness	26%	56%

Table 7 Summary of Annual EMCs (mg/l)

LANDUSE	BOD	TSS	TDS	COD	NOX	TKN	TP	DP
Residential	7.0	38.5	103.1	52.0	0.20	1.67	0.29	0.07
Commercial	11.1	24.7	37.6	62.8	0.66	1.33	0.24	0.15
Agricultural	8.0	132.0	192.0	103.0	0.24	1.47	1.00	0.23
Streets	9.7	104.0	30.0	94.0	0.74	1.65	0.33	0.17
Park/Undeveloped	8.0	78.0	30.0	45.0	0.61	1.08	0.14	0.03

3.3.1.3 Utility/Applicability

PLOAD can be a useful screening tool for targeting small watershed areas that may be contributing large pollutant loads. However, it is not suitable for planning or site development exercises. Because the user has the choice of using export coefficients or event mean concentration data, urban, rural and mixed-use watersheds can all be modeled. Because this is an empirical model that calculates loads based only on impervious values, pollutant concentration, and runoff volume, the results are best used to compare the pollutant loads of different watersheds or the same watershed under differing land use scenarios. The utility of absolute predictions using PLOAD will depend on the accuracy of the impervious values for land uses and the event mean concentration data. Although the model allows for the evaluation of the effects of BMPs, it does not consider the absolute location of these BMPs, and it relies on literature values of effectiveness to determine the sum of pollutant removal by all the BMPs within a watershed. Hampton Roads localities may continue to utilize PLOAD as a screening tool, but a more sophisticated modeling tool is needed in order to address the land use planning and stormwater management demands placed on the localities.

3.3.2 BMP/LID DSS

The BMP Decision Support System is a useful tool not only for evaluating the impact of land use changes on pollutant loading, but also for determining the most cost effective options for the placement of BMPs to maximize pollutant runoff in urbanizing watersheds. The BMPDSS includes both conventional and LID-type BMPs. The system uses the ArcGIS interface and requires ArcMap and Spatial Analyst. This interface allows the user to read and edit spatial and temporal datasets, place and configure BMPs, delineate drainage areas, and establish a routing network. A user's guide, step-by-step application guide, and case study of the Anacostia River watershed are included with the modeling software.

3.3.2.1 Data Requirements

The system requires a land use data layer in grid format, a land use lookup table (containing land use code, land use name, and land use description), and drainage areas. Drainage areas can also be manually delineated within the GIS interface or the system can automatically delineate watersheds if topography and hydrography data are available. Additionally, a unit area-based time series specific for each land use type is necessary because the system does not currently simulate runoff, flow, and nutrient or sediment time series. This time series should be from observations or a calibrated watershed simulation model such as HSPF. The previously developed time series data for Prince George's County, Maryland are included in the installation package. In order to simulate the effect of BMPs, location and configuration data are necessary. The BMP simulation module guides the user through setting the specifications for each BMP type.

3.3.2.2 BMP Simulation Module

The BMP simulation module uses process-based algorithms to simulate BMP function and removal efficiency. Process-based algorithms include weir and orifice control structures, storm swale characteristics, flow and pollutant transport, flow routing and networking, infiltration and saturation, evapotranspiration, and a general loss/decay representation for a pollutant. BMP effectiveness can be evaluated and estimated over a wide range of storm conditions, site designs, and flow routing configuration approaches.

Figure 6 illustrates the processes currently incorporated in the BMPDSS system. These include infiltration, orifice outflow, controlled orifice release (the user can define an hourly outflow rate, and there is an on/off switch), weir-controlled overflow spillway, underdrain outflow, bottom slope influence, bottom roughness influence, general loss or decay of pollutant (due to settling, plant uptake, volatilization, and so forth), pollutant filtration through the soil medium (represented by underdrain outflow), and evapotranspiration. The major BMP types that can be represented in the current version are storage-type devices (such as rain barrels, cisterns, and detention basins), bio-retention basins, filters, and swales (Figure 7). Additional BMP types, processes, or enhanced simulation techniques will be added in future versions.

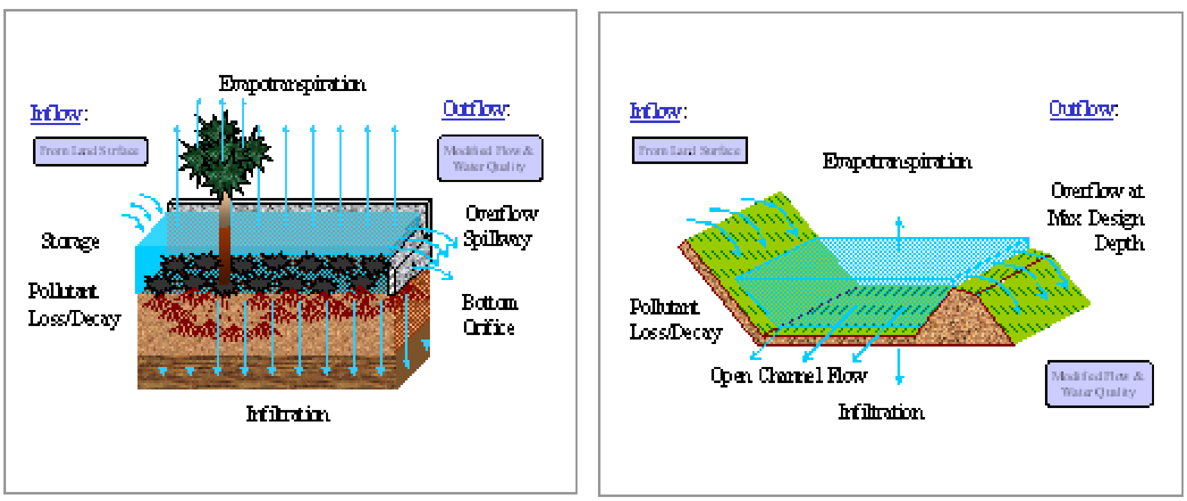


Figure 6 Major processes simulated in the BMP module (Source: BMP/LID DSS Users' Manual)

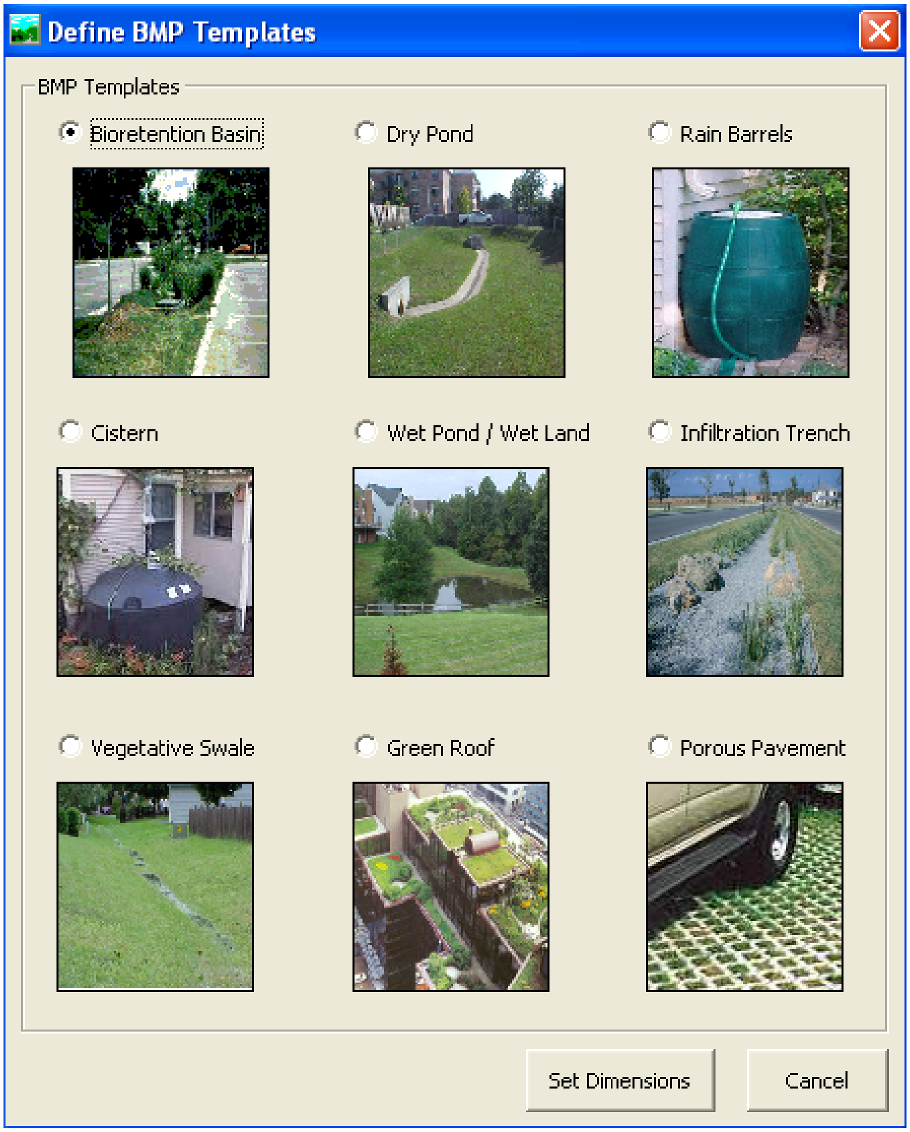


Figure 7 BMP Types Represented in BMP/LID DSS

3.3.2.3 Routing and Transport Module

Flow and pollutants are routed through the pipes or channels in a routing network with the user's choice of cross section by using the Storm Water Management Model (SWMM) (version 5) transport algorithms. The SWMM-Transport module tracks the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period.

Flow routing within a conduit link is governed by the conservation of mass and momentum equations for gradually varied unsteady flow (i.e., the St. Venant equations). The SWMM-Transport module uses the kinematic wave routing scheme to solve the continuity equation, along with a simplified form of the momentum equation in each conduit. This can result in attenuated and delayed outflow hydrographs as inflow is routed through the channel. However, this form of routing cannot account for backwater effects, entrance/exit losses, flow reversal, or pressurized flow. It can usually maintain numerical stability with simulation time steps of 5 to 15 minutes.

Water quality routing within conduit links assumes that the conduit behaves like a continuously stirred tank reactor (CSTR). The concentration of a constituent exiting the conduit at the end of a time step is found by integrating the conservation of mass equation, using average values for quantities that might change over the time step, such as flow rate and conduit volume. Input flows and pollutant loadings from external and dry weather inflows are supplied through time series data associated with a particular junction of the conduit inlet.

3.3.2.4 Optimization Component

The optimization component provides optimization techniques to identify the most cost-efficient BMP selection and placement strategies based on user-defined decision criteria, including assessment points (locations) and evaluation factors (flow and water quality). The function of the optimization engine is to determine the locations, types, and design configurations of the BMPs that best satisfy the user-defined water quality, water quantity, or cost objectives within user-defined constraints. The system provides an evaluation factor pick-list from which the user can choose. In the current version, the following factors are provided:

- Water Quantity Evaluation Factors
    - Annual Average Flow Volume (AAFV)
    - Peak Discharge Flow (PDF) within simulation period
    - Flow Exceeding Frequency (FEF) for user-specified threshold rate
- Water Quality (sediment and other user-specified pollutants) Evaluation Factors
    - Annual Average Load (AAL)
    - Annual Average Concentration (AAC)
    - Maximum Moving Average Concentration (MAC) for a user-specified time period.

Each evaluation factor can be presented in three modes: (1) percent of existing condition, (2) scaled between pre-developed and existing condition, and (3) value. As an important factor in optimization formulation, the cost function estimates the total costs of the BMP systems. A generic cost function is employed to provide relationships between BMP cost and excavation volume; a linear land cost term is also included.

The optimization component currently employs scatter search as the solution algorithm. The approach is designed to incorporate strategic responses, both deterministic and probabilistic, that take evaluation and history into account. Scatter search focuses on generating relevant outcomes without losing the ability to produce diverse solutions because of the way the generation process is implemented (Laguna and Marti, 2002). The objective function magnitude, instead of derivative information, is used directly in the search, thereby allowing them be applied to nonconvex, highly nonlinear, and complex problems. The scatter search approach does not emphasize randomization, particularly in the sense of being indifferent to choices among alternatives. Because of this feature of scatter search, for optimization problems that have a CPU time-consuming evaluator, it is expected that scatter search can find the near-optimal solution more efficiently and serve as a better optimization engine. In future versions, an alternative solution technique will be provided

3.3.2.5 Urban test case

The BMP Decision Support System was applied to the same urban test case watershed as described in Section 3.3.1.1. Due to a Corps of Engineers Restoration Study being conducted in the Lynnhaven River Watershed, updated land use and impervious data were available from URS Corporation for input into the BMPDSS model (

Table 8). A map of the updated land use is provided in Figure 8. Existing BMP configuration data were available from the City of Virginia Beach SWMM model.

It was expected that external time series from the calibrated HSPF model for this section of the Lynnhaven River Watershed would also be available. Due to extenuating circumstances, this data was not available in time, so the supplied time series data for Prince George's County, Maryland was used instead. The simulation period was January through December 1998. Both study areas have similar climates and land uses. Differences in total rainfall and temporal distribution were considered when evaluating the model results. When the HSPF model time series for the Lynnhaven become available it will be applied to the BMPDSS model for the urban test case watershed. Lack of high frequency monitoring data also made it difficult to validate the model results. PLOAD was used to estimate pollutant loadings using the updated land use information. These loads were then compared to the BMPDSS load estimates.

Table 8 Land Use Summary and Percent Impervious Area

Land Use	Acres	Percent Area	Percent Impervious Area
BMP	0.83	0.6%	100
Business	28.28	18.8%	73
Church	2.98	2.0%	47
Multifamily Medium Density Residential (MF)	54.25	36.1%	37
Office	2.21	1.5%	71
Open Space	4.50	3.0%	1
Park	0.25	0.2%	5
Single Family Medium Density Residential (SFM)	23.95	15.9%	21
Street Network	22.87	15.2%	6
Water	10.28	6.8%	100
Total	150.41		

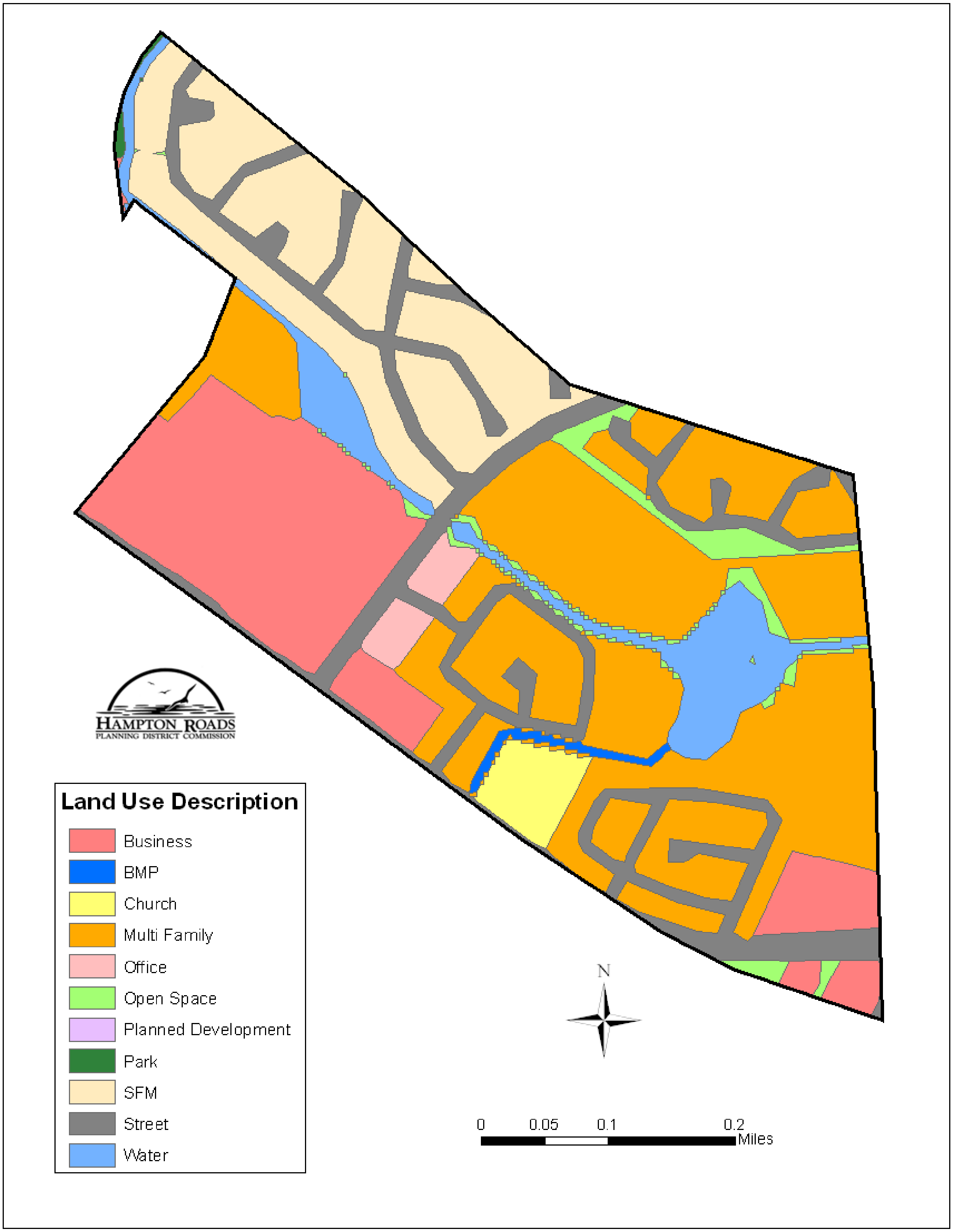


Figure 8 Updated Land Use for Urban Watershed

3.3.2.6 Model Scenarios

The City of Virginia Beach was interested in modeling potential retrofit and redevelopment scenarios within this watershed. The pollutant load and runoff volume resulting from the current land use and existing BMP was modeled using land use data from URS and BMP data provided by the City of Virginia Beach. The configuration data for the existing wet pond is available in Figure 9. The detailed watershed routing for this scenario is visible in Figure 10.

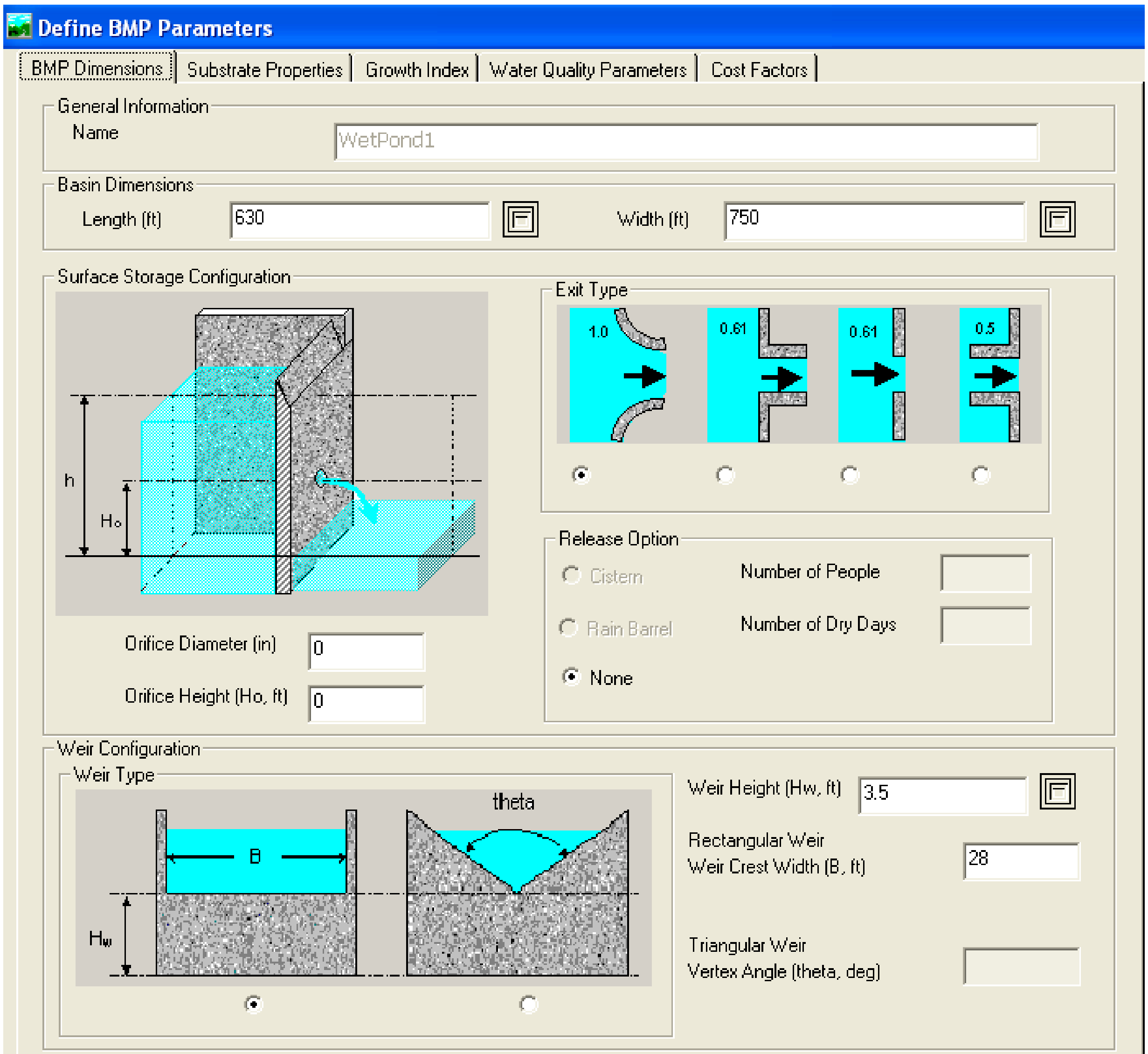


Figure 9 Configuration for existing wet detention pond

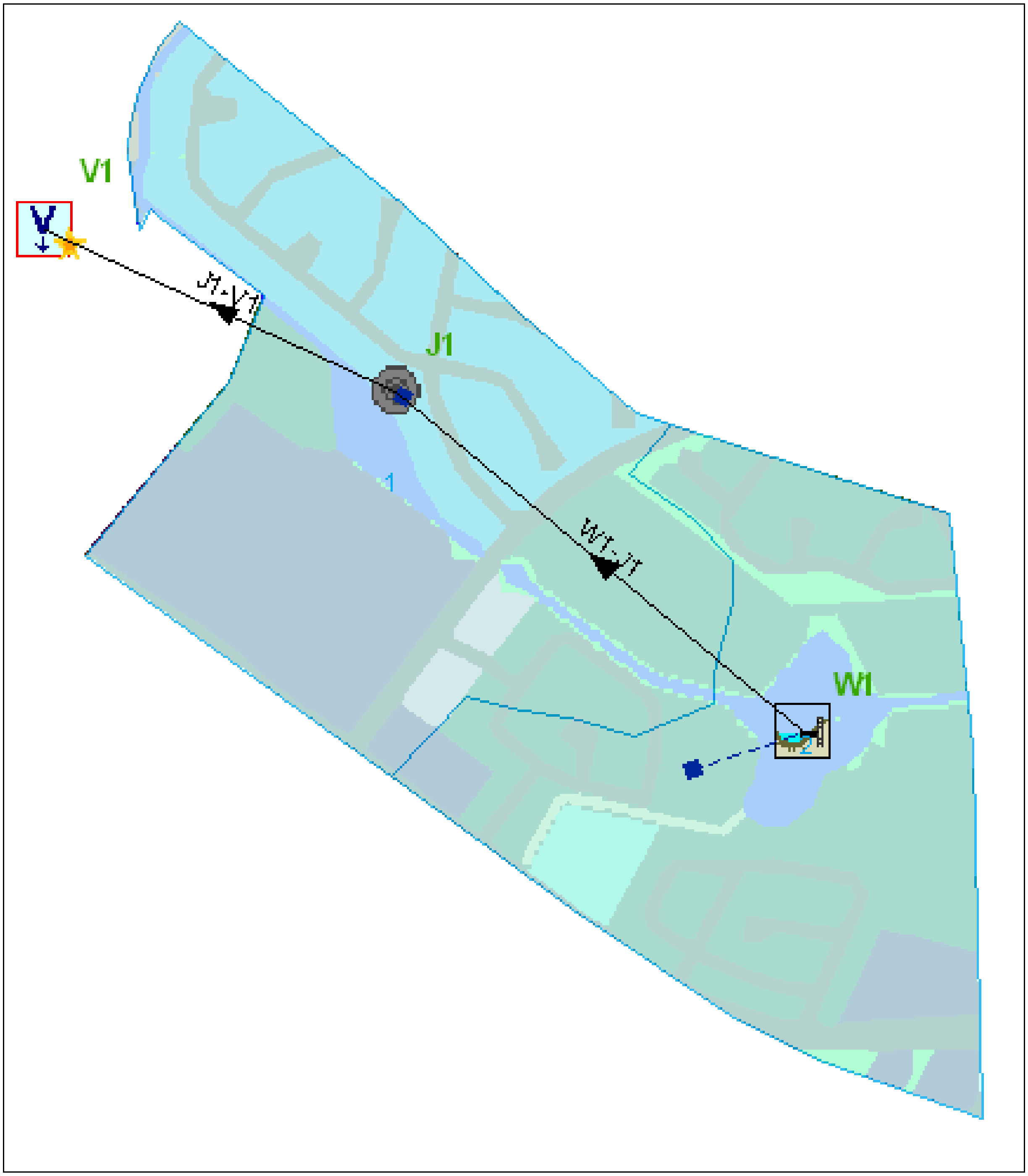
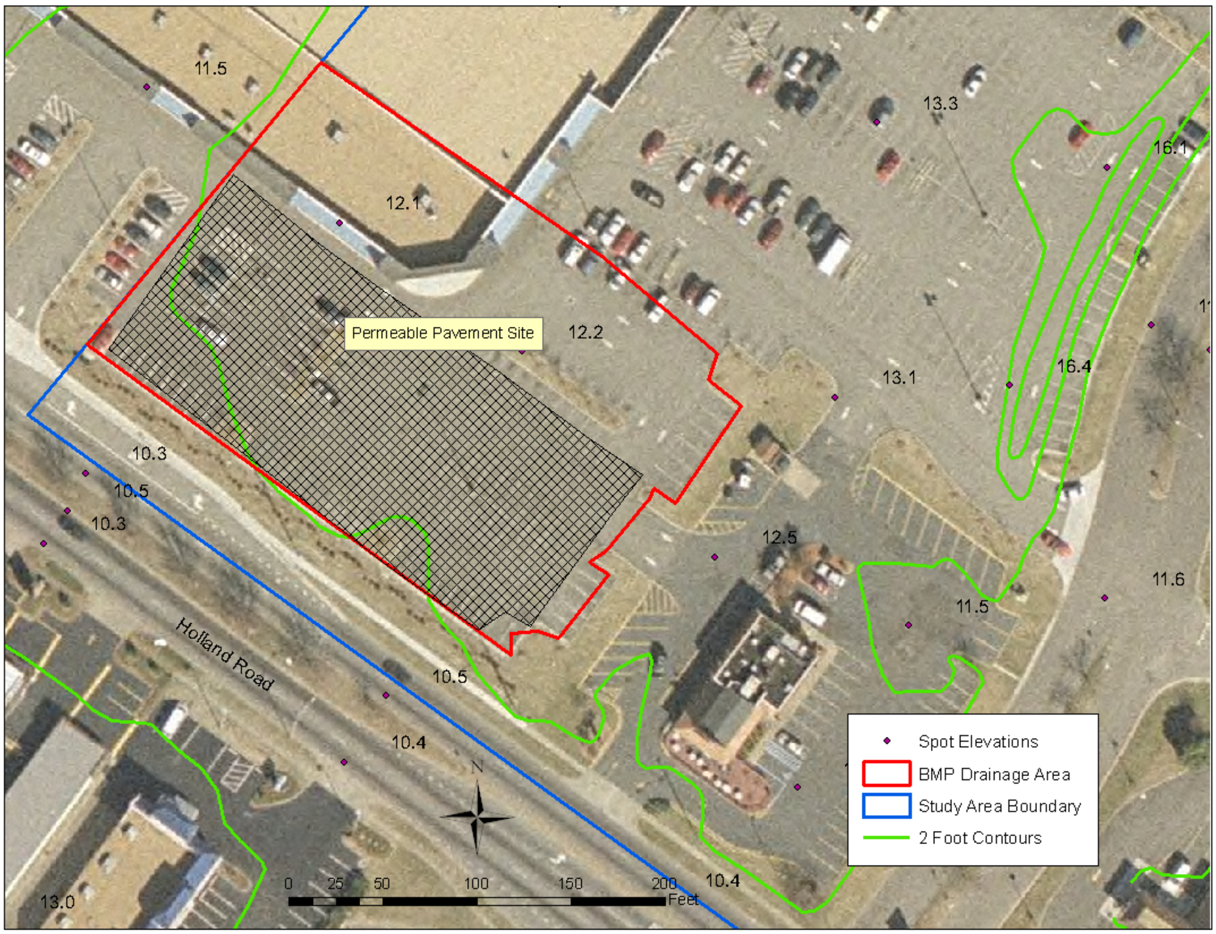


Figure 10 Routing Schematic for Current Scenario

In addition to modeling the current condition of the watershed, two potential BMP retrofit scenarios were modeled. These scenarios were designed after discussions with City of Virginia Beach staff. The first alternative scenario modeled was the placement of permeable pavement in the side parking lot of the existing Food Lion Shopping Center on Holland Road. The drainage area for this BMP was delineated using aerial photography, 2-foot contours, and spot elevation data (Figure 11). Detailed configuration data for the pavement are provided in Figure 12- Figure 15. The detailed watershed routing for this scenario is visible in Figure 16.



Aerial Imagery © 2002 Commonwealth of Virginia

Figure 11 Proposed Site for Permeable Pavement

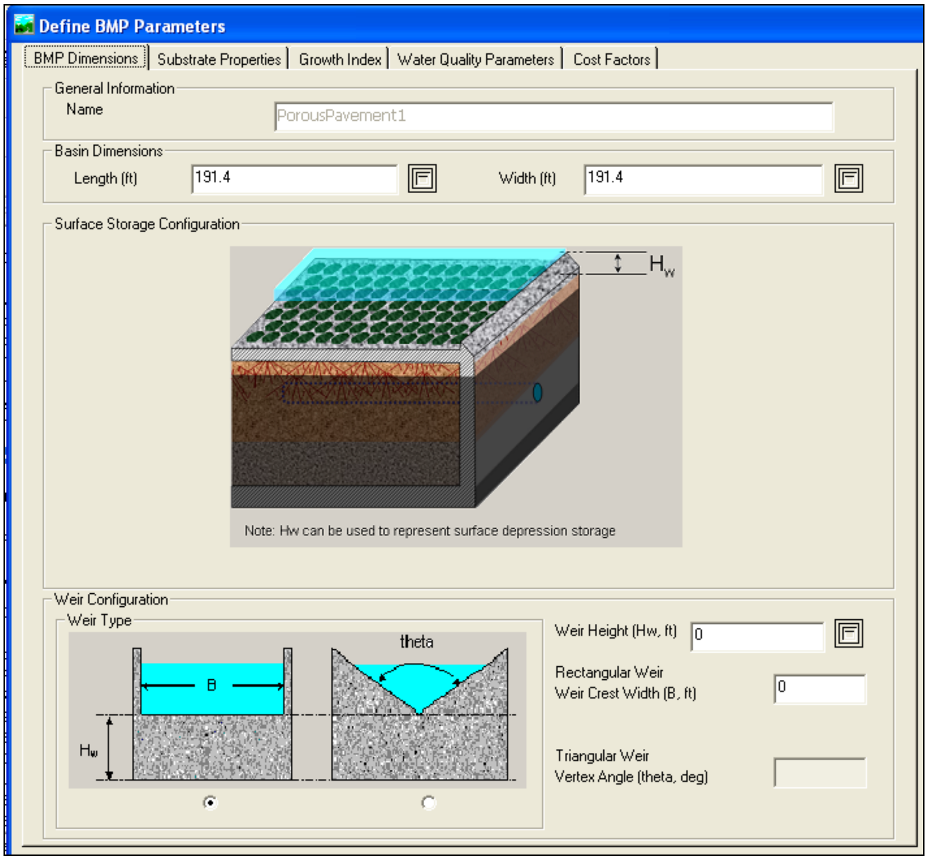


Figure 12 Specifications for Permeable Pavement

The Holtan Infiltration Equation adapted for underdrain flow (f = GI $AS_a^{1.4} + f_c$) is used to simulate the effects of the permeable pavement. Where f is the infiltration capacity (in/hr), GI is the growth index of crop in percent maturity varying from .1 to 1.0 during the season, A is the infiltration capacity (in/hr) per $(in)^{1.4}$ of available storage and is an index representing surface-connected porosity and the density of plant roots which affect infiltration, S_a is the available storage in the surface layer in inches, and f_c is the constant infiltration rate when the infiltration rate curve reaches a steady state (ASCE 1996). Values for these variables for the permeable pavement were the taken from the Anacostia River Case Study provided with the BMP/LID DSS Model.

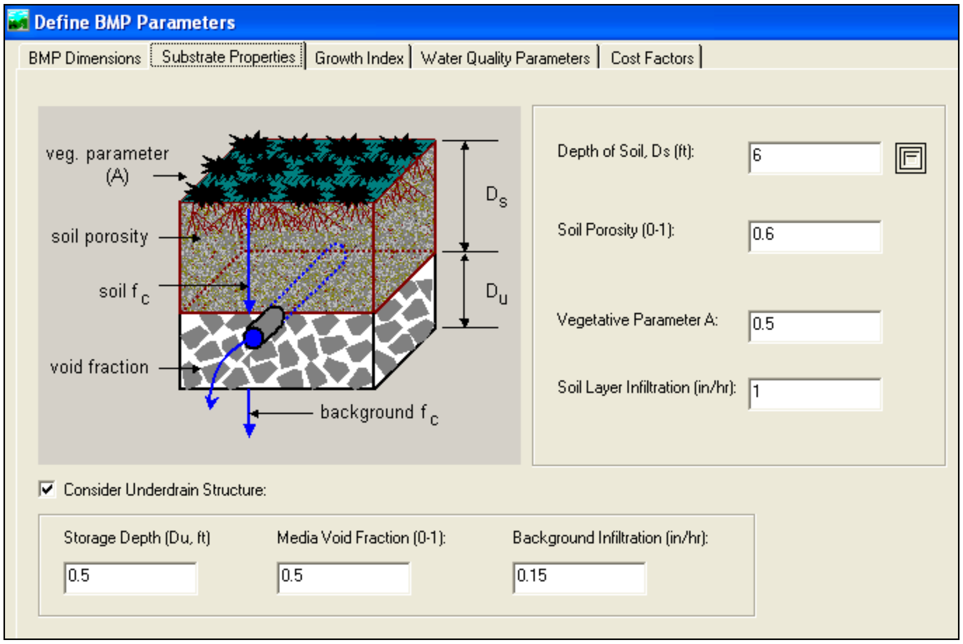


Figure 13 Substrate Properties for Permeable Pavement

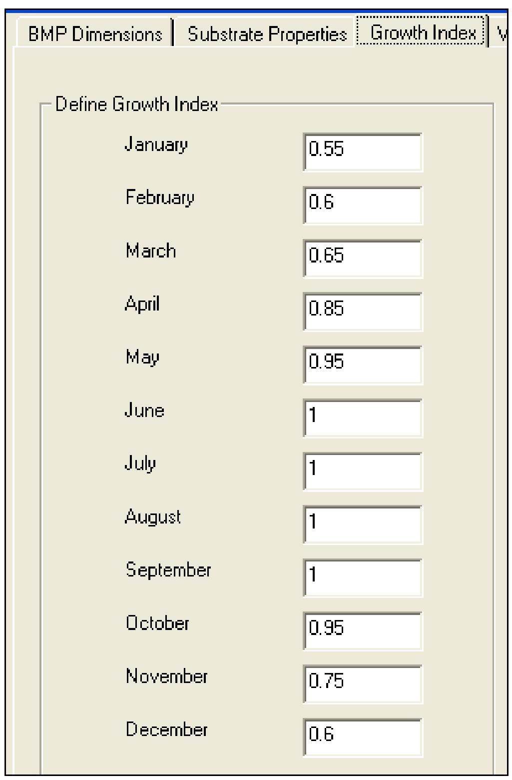


Figure 14 Growth Index Properties for Permeable Pavement

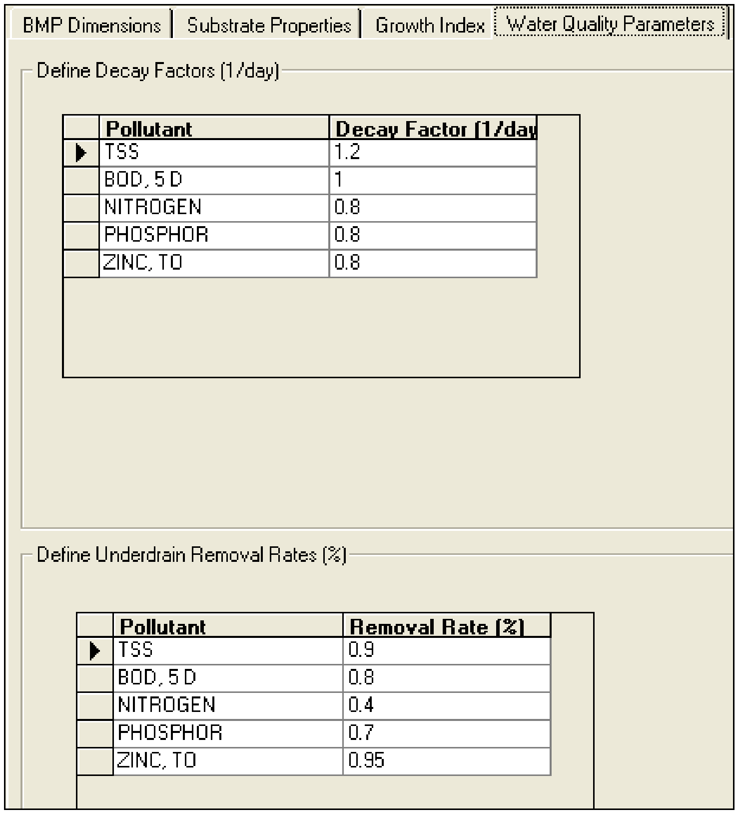


Figure 15 Water Quality Parameters for Permeable Pavement

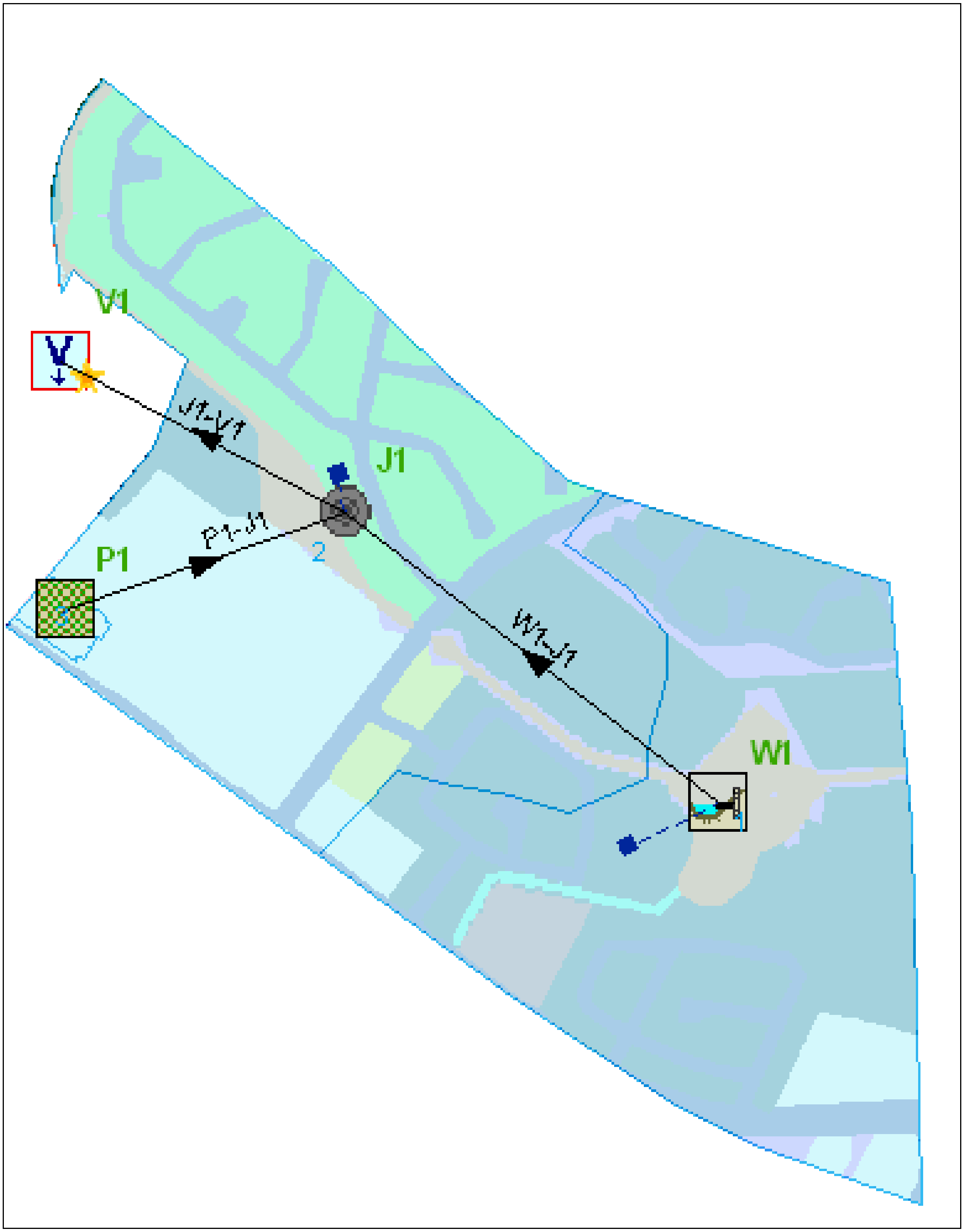


Figure 16 Detailed Routing Schematic for Permeable Pavement Scenario

The second alternative scenario modeled was the addition of two small bio-retention cells in the parking lot of the shopping center adjacent to the Food Lion on Holland Road. The drainage areas for these BMPs were delineated using aerial photography, 2-foot contours, and spot elevation data (Figure 17). Detailed configuration data for the bio-retention basins are provided in Figure 18 - Figure 21. The detailed watershed routing for this scenario is visible in Figure 22.

Aerial Imagery © 2002 Commonwealth of Virginia

Figure 17 Proposed Site for Bio-retention Cells

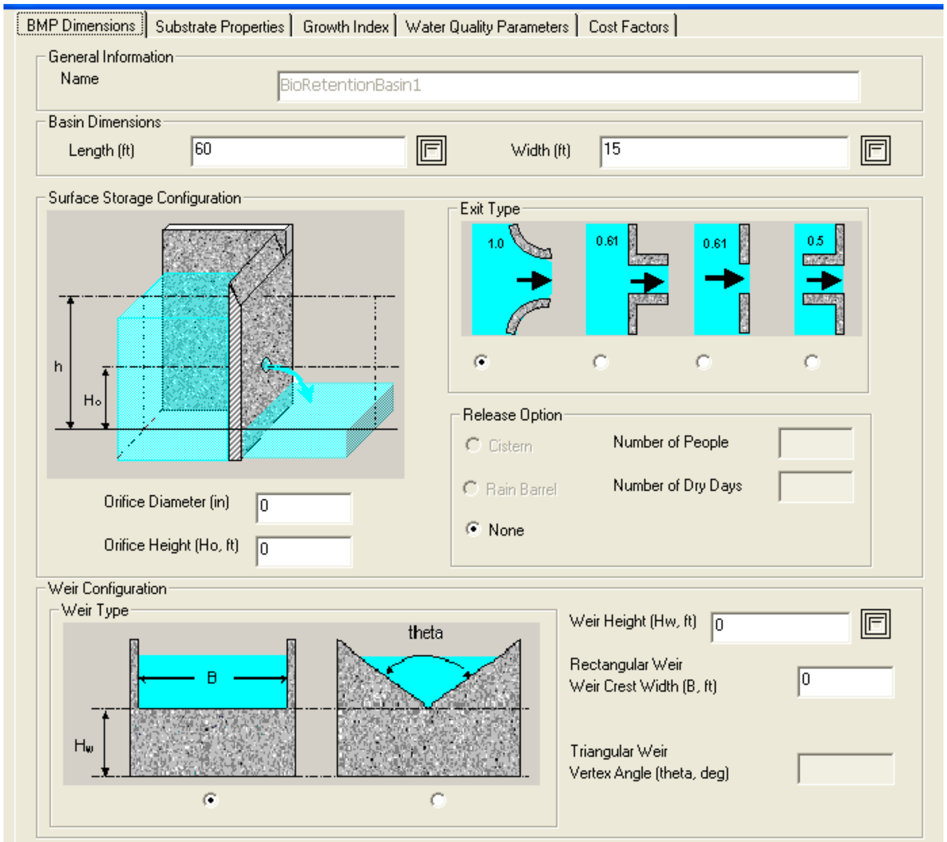


Figure 18 Dimensions of Bio-retention Cells

The Holtan Infiltration Equation adapted for underdrain flow (f = GI $AS_a^{1.4} + f_c$) is used to simulate the effects of the bio-retention basins. Where f is the infiltration capacity (in/hr), GI is the growth index of crop in percent maturity varying from .1 to 1.0 during the season, A is the infiltration capacity (in/hr) per $(in)^{1.4}$ of available storage and is an index representing surface-connected porosity and the density of plant roots which affect infiltration, S_a is the available storage in the surface layer in inches, and f_c is the constant infiltration rate when the infiltration rate curve reaches a steady state (ASCE 1996). Values for these variables for the bio-retention basins were the taken from the Anacostia River Case Study provided with the BMP/LID DSS Model.

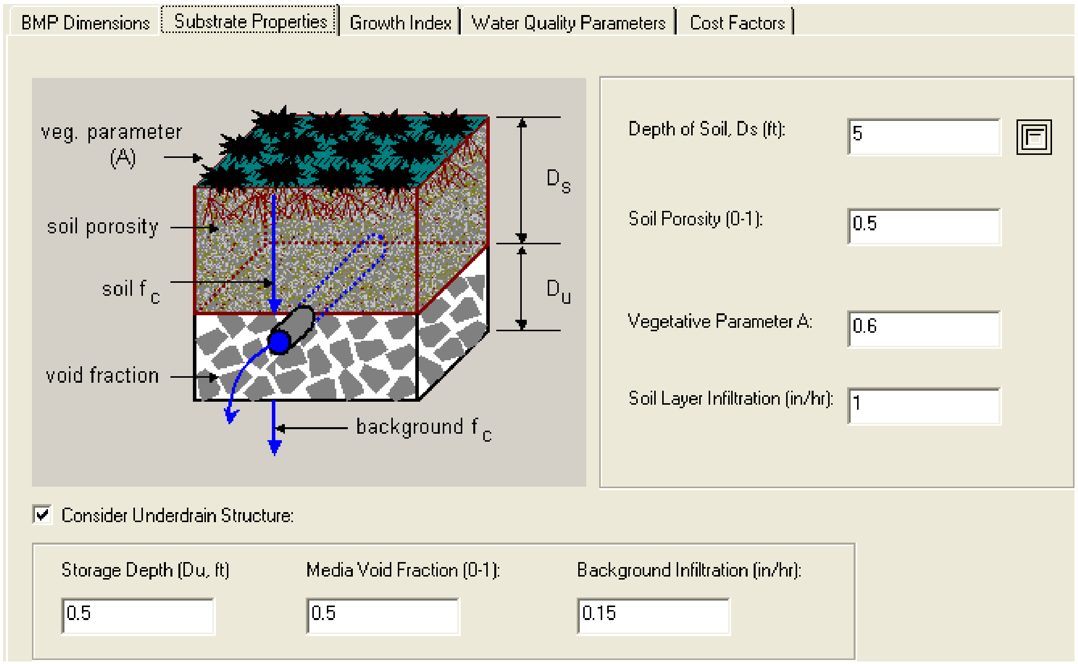


Figure 19 Substrate Properties of Bio-retention Cells

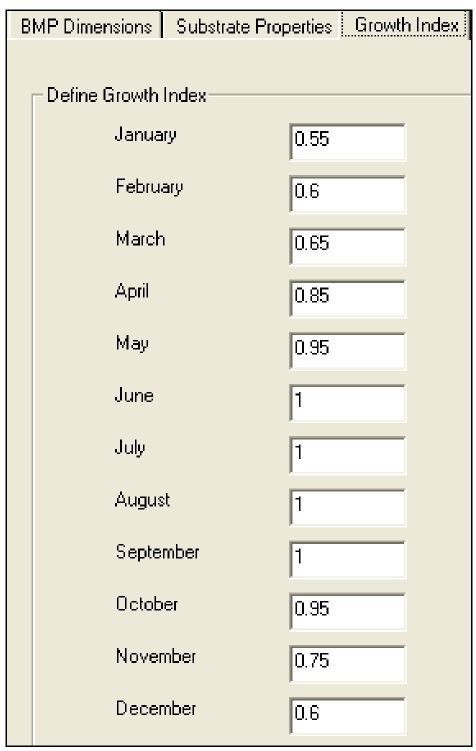


Figure 20 Growth Index for Bio-retention Cells

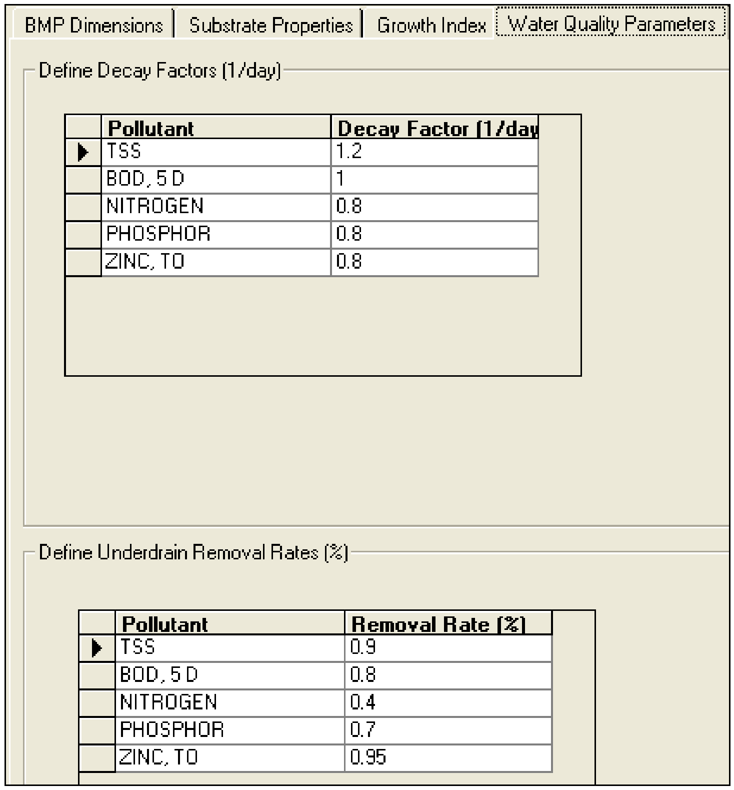


Figure 21 Water Quality Parameters for Bio-retention cells

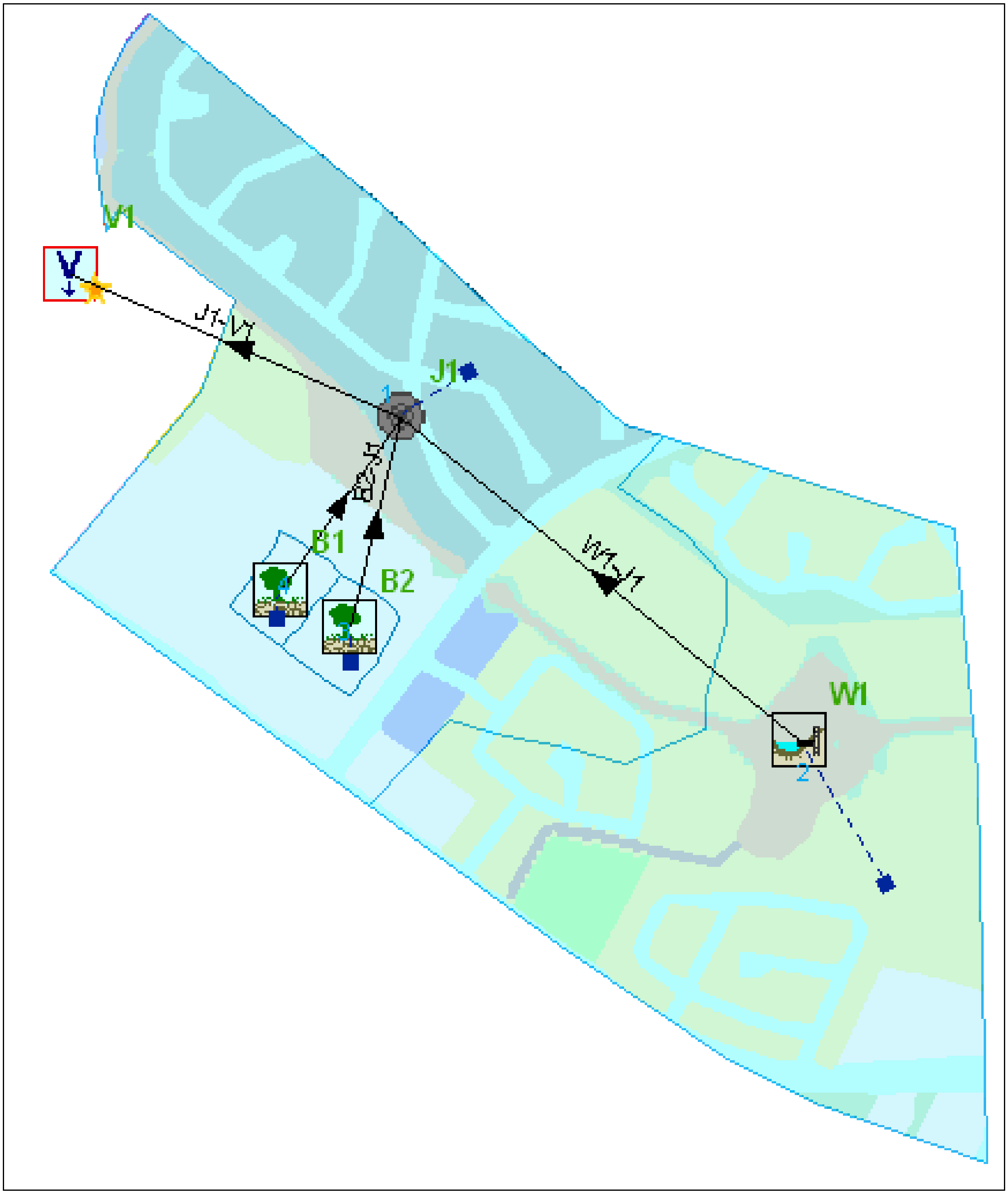


Figure 22 Detailed Routing Schematic for Scenario 3

3.3.2.7 Results

The results of the pollutant loading analysis using the BMP/LID Decision Support System are displayed in Table 9. Due to data availability limitations, these results were calculated using time series data that was calibrated for Prince George's County, Maryland rather than the City of Virginia Beach. The use of this data precludes individual storm analysis, but still allows for estimates of annual pollutant loads.

In order to determine the accuracy of these estimates of annual pollutant loads, total rainfall data during the simulation period (1998) were compared for Prince George's County, Maryland and the City of Virginia Beach. Total measured rainfall was 44 inches in Prince George's County, Maryland and 55 inches in Virginia Beach at the Oceana Naval Air Station weather station. Given the slight disparity in measured rainfall between the two localities, it is expected that actual pollutant loadings for the simulation were higher than these estimated loads. However, average annual rainfall for Virginia Beach is 45 inches, so these pollutant loads may be representative of average conditions at least in terms of total runoff.

Due to a lack of monitoring data for this study area, pollutant load estimates were compared to PLOAD estimates for the same watershed under the same rainfall conditions. Even though the estimated pollutant removal efficiencies of the wet pond are different between the two models for all the pollutants, the total load estimates are similar for all constituents except total suspended solids (TSS). The total flow estimates were within 6 percent of each other. With the effects of the BMP, biochemical oxygen demand (BOD) estimates were within 2 percent of each other, nitrogen estimates within 10 percent, and phosphorus results were less than 8 percent different. This comparison provides some confidence that the results of this analysis are reasonably accurate.

While it is important to consider the absolute accuracy of the modeling results, it is also important to consider the relative results the model can provide in order to compare the pollutant loadings between scenarios. The BMP/LID DSS model has been tested, calibrated, and validated in other test cases, and the included BMPs have been field tested for pollutant removal efficiency. Provided the specifications for the modeled BMPs are accurate, these results can be used to determine the potential cost effectiveness of installing the prescribed BMPs.

Table 9 shows that the bio-retention ponds outperform the permeable pavement in the removal of sediment, BOD, nitrogen, and phosphorus. The permeable pavement does a better job of reducing the average annual flow, but the bio-retention ponds have a greater impact on the peak daily flow. Table 11 shows that the permeable pavement costs 7.5 times more than the bio-retention ponds. The bio-retention ponds are the more cost effective solution for reducing pollutant loads in this test watershed.

Table 9 Results of BMP/LID DSS Model Scenarios

BMP Scenario	Average Annual Flow Volume (ft^3/yr)	Peak Daily Flow (cfs)	TSS (tons/yr)	BOD5 (lbs/yr)	Nitrogen (lbs/yr)	Phosphorus (lbs/yr)
Existing Land Use without BMP	9677609	30	513	5330	911	121
Existing Land Use with Wet Pond	8023106	21	331	3005	517	65
Wet Pond Percent Reduction	17.1%	29.2%	35.6%	43.6%	43.3%	46.0%
With Pond and Pavement	7916054	21	321	2969	507	64
Percent Reduction of Permeable Pavement	1.3%	2.0%	3.0%	1.2%	1.9%	1.4%
With Pond and Bio-retention Ponds	7957573	20	299	2894	491	63
Percent Reduction of Bio-retention Ponds	0.82%	5.72%	9.46%	3.70%	4.99%	4.14%

Table 10 PLOAD Results for Urban Watershed

Scenario	Flow (ft^3/yr)	TSS (tons/yr)	BOD (lbs/yr)	TKN (lbs/yr)	TP (lbs/yr)
Without BMP		9.4	4,362	715	120
With BMP	8,499,138	.945	3,054	572	60
%Removal by BMP		90%	30%	20%	50%

Table 11 Cost functions for selected BMP/LID practices

BMP Type	Cost Function [a]	Scenario Cost	Reference
Bio-retention Ponds	Cost ($) = 5.3 x volume + 500	$48,700	USEPA 1999a
Porous pavement	Cost ($) = 10 x surface area + 500	$365,310	USEPA 1999b

[a] Volume is in cubic feet, and area in square feet.

3.3.2.8 Discussion of utility and applicability

Although it is difficult to determine the accuracy of the modeling results using the currently available data for this case study, the BMP/LID Decision Support System is a relatively easy to use tool that may prove useful for watershed modeling in the Hampton Roads region. This tool could be used to estimate the pollutant reduction resulting from the scenarios prescribed in a TMDL Implementation Plan for an impaired watershed. It could also be used to determine the impact of development scenarios and if proposed development plans meet target on-site nutrient reduction goals. However, until higher frequency monitoring data or HSPF time series are available in areas of Hampton Roads, this model may be of limited use for estimating accurate pollutant concentrations. When time series data for the Lynnhaven Watershed become available this spring, the model scenarios above will be rerun with this site-specific data. Comparison of these new results to the results above will highlight the necessity of using calibrated site-specific time series data to determine pollutant loads. Efforts will be made to determine if the time series can also be used in watersheds with similar land use composition throughout Hampton Roads. As TMDL development efforts in Hampton Roads intensify, monitoring data and HSPF output data may become more readily available for many of the localities.

3.4 Recommended Steps in Development of a Regional Watershed Modeling Program for Hampton Roads

One of the primary goals of this project is the identification of the components and structure of a regional watershed-modeling program for Hampton Roads. Many of the components needed for a regional program are already in place, however a significant effort will be required to assemble a cohesive program. Needed elements of a regional program include appropriate computer software and hardware, a regional technical advisory committee, training for staff to develop the expertise to set up the models and evaluate the output, and a library of digital data to support the modeling work. Given the complexity of this undertaking it will likely be a multi-year effort to bring it to fruition.

The HRPDC staff currently carries out economic, transportation and ground water modeling for the region. Building on this structure the watershed modeling program could be carried out by the HRPDC staff in conjunction with the existing environmental committees. This approach would require training of existing staff and partnership with other agencies that have watershed modeling expertise. Depending on the scope and goals for the program it may be necessary to hire additional staff or contract for consultant services to address the more technical aspects of program start up.

3.4.1 Refinement of Program Goals

As previously mentioned, the modeling program will be used for a wide variety of regulatory compliance and land use planning initiatives. Before moving forward with the development of a regional modeling program it will be necessary to work closely with the Hampton Roads localities, and in particularly the stormwater utilities, to refine and clearly articulate a set of goals for the modeling program.

3.4.2 Establishment of a Technical Advisory Committee

A Technical Advisory Committee will be needed to support the development of a regional modeling program. Coordination of a broad range of agencies and expertise will help to insure that the modeling program benefits from all of the knowledge and resources available in the region. Possible participants include the following:

Federal Government: USACE, USEPA, USGS, USFWS

State Government: DEQ, DCR

Regional Planning: HRPDC

Local Government: Hampton Roads Localities

The Technical Advisory Committee will provide advice on the structure and goals for the modeling program, recommendations on the tools to use, provide expertise on resources available in the community and critique the program once it is up and running.

3.4.3 Selection of a Suite of Modeling Tools

The primary goals of this grant were the evaluation of a range of watershed modeling tools and the identification of a set of tools that best address the needs of the Hampton Roads communities. The needed modeling capabilities range from general evaluation of watershed characteristics to comparison of specific management alternatives. The modeling requirements are further complicated by the variation in land uses across Hampton Roads. The central city areas such as downtown Hampton, Newport News, Norfolk, and Portsmouth are urban and largely built out. The more rural areas such as Isle of Wight, Gloucester, Southampton County, and Surry are a mix of large lot residential, agricultural and forested land uses. The tools selected for the modeling program must be able to handle this broad range of land uses and be able to predict the ramifications of various future land use scenarios. In addition, the selected tools must be able to evaluate the effectiveness of various best management practice (BMP) combinations.

Given the results of the investigations undertaken as part of this project and work underway at other agencies the following recommendations for a suite of modeling tools are offered.

- Continue the use of PLOAD as a screening tool and general indicator of watershed conditions:
- Develop a regional capability for the use of HSPF for applications that require the evaluation of various management scenarios.
- Continue development of BMP/LID capability to evaluate LID options and assessment of associated costs.

Each of these options is discussed in the following section.

PLOAD

Many of the Hampton Roads localities have an investment in running PLOAD as a requirement of their NPDES permits. Continuation of this capability will allow comparison with previous runs and provide a snapshot of change over time. This capability could be expanded to the entire region and would allow general assessment of the role of land use change in generation of nonpoint source pollution.

HSPF

The prevalent use of HSPF in both the Chesapeake Bay Program and TMDL development provides an incentive for its inclusion in a regional modeling program. Combined with the fact that HSPF is perhaps the most capable and well tested watershed model available it must be considered as an important tool for detailed examination of watershed management alternatives. Much of the groundwork for the use of HSPF as a regional tool will be laid with the development of the Phase Five Chesapeake Bay watershed model. This and the BASINS implementation of HSPF should be examined as candidates for inclusion in a regional modeling system.

Several problems associated with the use of HSPF include the fact that the Bay Program version has evolved separately from the versions supported in the BASINS and interoperability between the two is almost impossible.

BMP/LID

BMP/LID was developed as a tool to evaluate and compare low impact development (LID) practices. The Hampton Roads localities will be encouraged and perhaps required to include LID in the suite of management practices that they employ in the near future. Inclusion of BMP/LID in a regional modeling program will provide the capability to evaluate LID options and associated costs.

3.4.4 Development of staff expertise in model application

Development of staff expertise is essential to running a credible watershed modeling program, particularly if detailed models are required to address specific watershed management questions. Training and collaboration with other agencies working in this realm will be necessary. The Chesapeake Bay Program is in the process of developing the Phase Five version of the watershed model. As the Phase Five model and the associated Community Modeling Program become available it will be important for the HRPDC staff to be involved in any training that is offered. Also of importance are training opportunities associated with the release of the next version of BASINS. BASINS is currently being rewritten to remove the dependency on ESRI’s ARCVIEW software. Once the new version is released the USEPA will restart the BASINS training program.

3.4.5 Development of a library of information to support the modeling effort

A successful watershed modeling program is dependant on a significant quantity of digital information to describe conditions in the watershed during the time period modeled. This information can be divided into three categories; watershed characterization data such as land use, impervious surfaces and soils data, state variables such as adsorption/desorption coefficients and potency factors for pollutants and input variables such as precipitation and evaporation rates.

The HRPDC GIS program has resulted in the collection of a significant set of geographic information for the Hampton Roads region. The majority of this information is watershed characterization data. These data could be augmented to establish a digital library of information to support a regional modeling program. Information currently housed at the HRPDC includes land use/land cover, national wetland inventory, hydrology, soils, digital orthophotography, future land use maps, utility infrastructure, green infrastructure, transportation networks, and jurisdictional boundaries.

3.4.6 Calibration and Verification

Calibration and verification will be critically important in developing confidence that the selected modeling tools are correctly representing watershed conditions found in Hampton Roads. In the case of the HSPF model, the Phase Five Chesapeake Bay modeling program will be an important source of calibration information. As smaller watersheds are examined it may become necessary to augment these data.

3.4.6.1 Enhancement of Watershed Monitoring Programs

Virginia’s Department of Environmental Quality is responsible for the majority of water quality monitoring that takes place in Virginia. It will be necessary to review the available data and determine their applicability for use in model calibration and validation. It may be necessary to enhance the monitoring network to support a watershed modeling program.

3.4.7 Problem Solving

Once the preceding steps are complete it will be possible to apply the modeling tools to a broad range of applications. Through documentation and augmentation of the regional “digital watershed” it will be possible to build a library of model runs and supporting watershed characterization data. This effort would position the Hampton Roads communities to evaluate and compare various management alternatives and quantify the pollutant loading impacts of land use change over time.

4.0 CONCLUSIONS AND RECOMMENDATIONS

A regional watershed modeling program has the potential to offer substantial benefits to the Hampton Roads localities. Given the level of effort required for program development, it will be necessary to proceed in a stepwise fashion to ensure that such a program is cost-effective and meets local goals. Based on literature review, analysis of various watershed modeling programs and testing of various watershed models the following conclusions and recommendations are offered:

- The HRPDC staff should continue discussions with the Hampton Roads localities on the development of a regional watershed modeling program.
- A technical advisory committee should be established to continue the process of articulating the goals and structure for a regional watershed modeling program.
- HRPDC staff should continue to closely monitor the evolution of various water quality regulatory programs and continue to investigate the application of watershed modeling to assist with regulatory compliance.
- HRPDC staff should continue to investigate the application of the BMP/LID and HSPF models in Hampton Roads.
- HRPDC staff should participate in training activities associated with the development and release of the Phase Five Chesapeake Bay watershed model and the associated Community Modeling Program.
- HRPDC staff should participate in BASINS training when the new version of BASINS is released.

Based on the continued discussions with Hampton Roads localities and the work of the technical advisory committee a final set of recommendations on the structure and goals for a regional watershed modeling program should be developed. At this point it will be possible to estimate the cost and level of effort associated with program startup. This is the point at which a regional decision should be taken on moving forward with a modeling program.

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